Klamath Hydroelectric Project
(FERC Project No. 2082)

Response to November 10, 2005, FERC AIR GN-2

Klamath River Water Quality Model Implementation, Calibration, and Validation

PacifiCorp
Portland, Oregon

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EXECUTIVE SUMMARY

To support studies for the relicensing of the Klamath Hydroelectric Project, PacifiCorp has used a hydrodynamic and water quality model of the Klamath River from Link dam to Turwar developed by Watercourse Engineering, Inc. Because of dramatically varying conditions along the river, and especially considering the very different hydrodynamics of steep river sections and reservoirs, different modeling systems were used to simulate river and reservoir reaches. River reaches were modeled with the Resource Management Associates (RMA) suite of finite-element hydrodynamic and water quality models. Reservoirs were modeled with U.S. Army Corps of Engineer's CE-QUAL-W2. Use of these two numerical models takes advantage of each model's strengths.

The Klamath River model developed for these studies is comprised of four river and four reservoir reaches. During simulation, the sub-models of each reach are run in series to produce linked results for the entire river system under varying hydrologic, water quality, and meteorological boundary conditions. The RMA water quality model RMA-11 was modified to improve linkage between the models. This report describes model selection, implementation, calibration, and validation.

The Klamath River model has been calibrated with data from 2000 and 2001 and validated considering data from 2002 through 2004. Over these five calendar years (2000–2004), simulation results are compared with observed data from 17 locations along its approximately 250-mile length running from Upper Klamath Lake, in Oregon, to the California coast. Calibration and validation included assessment of flow, temperature, dissolved oxygen, nutrients, and algae representation. Model performance varies among constituents with simulated flow and temperature conditions matching field observations well. The remaining constituents illustrate various degrees of departure from field data, depending on the reach and time of year. In some cases day to day conditions are not represented in the model, while longer-term conditions are generally replicated. The chemical and biological parameters often do not perform as well as the physical parameters of flow and temperature, because of the complex interaction among nutrients, primary production, dissolved oxygen, and other constituents. Not all of these processes are well defined for many river systems, the Klamath River included. Overall, model performance for the validation period – for all parameters – was consistent with calibration period performance. Because calibration of the model is a time intensive exercise, and because model performance during the validation period was consistent with performance during the calibration period, recalibration using the entire period has not been completed at this time.

Subsequently, the calibrated model has been applied to several management scenarios to assess existing conditions, effects of hydropower operations, or complete removal of hydropower facilities. These scenarios are described briefly here and in detail in other documents. Application and testing of the model have improved understanding of Klamath River limnology and provided insight into key processes and characteristics that affect water quality along the river's length. In particular, the model indicates that water quality of releases from Upper Klamath Lake to the Klamath River has a dominating effect on water quality throughout the system.

1.0 INTRODUCTION

To support studies for relicensing of the Klamath Hydroelectric Project (Project) (FERC No. 2082), PacifiCorp has used a hydrodynamic and water quality model of the Klamath River from Link dam to Turwar developed by Watercourse Engineering, Inc. This report describes model selection, implementation, calibration, and validation. Supporting documentation is found in attached appendices.

PacifiCorp conducted numerous meetings with the Water Quality Work Group (WQWG) over the last 2-plus years related to the water quality modeling processes. PacifiCorp has supplied detailed reports describing water quality methods, assumptions, and results. These documents were passed out at the meetings, and have also been placed on PacifiCorp's relicensing web site at (http://www.pacificorp.com/Article/Article1152.html). The WQWG retained Dr. Scott Well's of Portland State University to conduct a comprehensive peer review of the water quality model. Updates and modifications to the model were subsequently done in response to Dr. Wells' comments. PacifiCorp's responses to Dr. Wells' comments are documented in the FERC submittal GN-2. Also, the model has also been reviewed by Tetra Tech and additional modest modifications have been made. Watercourse Engineering, through discussions with EPA and other TMDL agents, is working closely with Tetra Tech to produce a single model version for all modeling activities in the basin (e.g., FERC, TMDL, others).

After selecting appropriate numerical models with which to represent the system, the models have been implemented in a process that includes gathering necessary descriptive data (including geometry, hydrology, water quality, and meteorology), formatting the data for input, and initiating model runs. In the course of implementation, default model parameters were selected and general model testing was done. During calibration, model parameters (e.g., rate constants and coefficients) were modified to fit the model to field observations. In validation, the model was tested on an independent set of boundary conditions to assess its ability to replicate system response using parameter values determined in calibration.

The calibrated and validated model has been applied to selected management strategies or scenarios. These scenarios represent varied flow or water quality conditions, and include the incremental removal of project facilities to identify potential impacts and outcomes. Results of this application help to demonstrate the relative response of the system to change with respect to existing conditions, and determine what effect, if any, the Project has on water quality. Results of model application and testing also provide insight into important characteristics and processes within the system.

Model implementation, calibration, and validation are described in this report. Application of the validated model to four scenarios is also described. Supporting information (including an overview of the model framework, model descriptions, geometry, boundary conditions, and procedures for processing data used in the models) is included in the appendices to this report.

1.1 STUDY AREA

The Klamath Hydroelectric Project (Project) is located along the upper Klamath River in Klamath County, south-central Oregon, and Siskiyou County, north-central California. The

Klamath River is one of only three rivers that bisect the Cascades mountain range, flowing from the interior of Oregon through California's coastal rain forest to the Pacific Ocean. The Klamath River begins at the outlet of Upper Klamath Lake at River Mile (RM) 254 in Oregon at elevation 4,139 feet and flows southwest to the Pacific Ocean at Requa, California. Upper Klamath Lake is a shallow, regulated, natural lake, which serves as a storage reservoir for irrigation of approximately 250,000 acres in the basin.

From Upper Klamath Lake, water flows into a relatively short 1.3-mile reach of the upper Klamath River called Link River located in the city of Klamath Falls. Downstream of Link River, the river flows through Keno Reservoir (including a section known as Lake Ewauna), which is the diked channel of what was once part of Middle and Lower Klamath Lake. An extensive array of canals feeds water to and from the river and surrounding farmland. The Lost River diversion channel, other diversions, and other major irrigation drains enter Keno reservoir. Keno dam controls water level in the reservoir.

Below Keno dam at Keno, Oregon, the river enters the Klamath River canyon at elevation 4,000 feet. The river in this reach is free flowing for about 5 miles to J.C. Boyle reservoir (elevation 3,800 feet). Spencer Creek is a small tributary that enters J.C. Boyle reservoir. From below J.C. Boyle dam, the river is free flowing for the remaining 22 miles of canyon before entering Copco reservoir in northern California (elevation 2,600 feet). Copco reservoir is about 4.3 miles long. Shovel Creek is another small but important trout-producing tributary that enters the river near the downstream end of the canyon.

Leaving Copco reservoir the Klamath River flows through a short section of canyon before entering Iron Gate reservoir. Iron Gate reservoir is about 6.0 miles long. Below Iron Gate dam, the river flows unimpounded the remaining 190 miles to the ocean. Fall Creek, a relatively small tributary, enters the Klamath River near the upstream end of Iron Gate reservoir. Jenny Creek is another small tributary that enters Iron Gate reservoir about 2 miles downstream of the mouth of Fall Creek

1.2 PROJECT FACILITIES

The existing Project facilities are located along a 64-mile length of the Klamath River between RM 190 and RM 254. The existing Project consists of six generating facilities along the main stem of the upper Klamath River, a re-regulation dam with no generation facilities, and one generating facility on Fall Creek, a tributary to the Klamath River at about RM 196. The Project that PacifiCorp proposes for relicensing consists of fewer facilities and will occur along a shorter 38-mile length of the river from RM 190 to RM 228. The upstream-most Eastside and Westside facilities will be decommissioned, and Keno dam will no longer fall under PacifiCorp's license because it serves no hydropower function.

Link River dam, located at RM 254, was completed in 1921. It provides regulation of Upper Klamath Lake, diverts water from the lake to the Eastside and Westside powerhouses, and releases a minimum flow to the Link River reach between the dam and the Eastside powerhouse. U.S. Bureau of Reclamation (USBR) owns Link River dam, but PacifiCorp operates the dam to maintain lake levels and release flows according to a contract between PacifiCorp and USBR. Operations must balance the requirements for threatened and endangered species found in Upper

Klamath Lake and downstream, irrigation, and power generation, while maintaining sufficient carryover storage. Should operations threaten irrigation supplies, USBR reserves the right to take over facility operation. As previously mentioned, these particular facilities are not part of PacifiCorp's proposed Project.

Keno dam is a re-regulating facility located at about RM 233, approximately 21 miles downstream of Link River dam. Construction of Keno dam was completed in 1967. PacifiCorp built the facility intending to produce hydroelectric power, but the facilities were never developed. The Keno development operates as a diversion dam to control elevations of Keno Reservoir for the USBR's Klamath Irrigation Project. The dam maintains a constant reservoir level that allows irrigators to withdraw water during the growing season despite fluctuation in discharge from variable agricultural return flows. Reservoir levels rarely fluctuate more than 6 inches seasonally, although the reservoir may be drawn down about 2 feet annually for 1-2 days to provide an opportunity for irrigators to conduct maintenance on their pumps and canals. As required in the existing FERC license (FPC 1956), PacifiCorp has an agreement with Oregon Department of Fish and Wildlife (ODFW) to release a minimum 200 cfs flow at the dam. Flows through Keno generally mimic instream flows downstream of Iron Gate dam and approach minimum flow levels only during critically dry water years. As previously mentioned, Keno dam is not part of PacifiCorp's proposed Project.

Below Keno dam the Klamath River is free-flowing for about five miles to J.C. Boyle reservoir. The J.C. Boyle development consists of a reservoir, dam, diversion canal, and powerhouse on the Klamath River between about RM 228 and RM 220. Construction was completed in 1958. The impoundment formed upstream of the dam (J.C. Boyle Reservoir) covers 420 acres and contains about 3,495 acre-feet of total storage capacity and 1,724 acre-feet of active storage capacity. The powerhouse is located about 4.3 RM downstream of the dam.

The J.C. Boyle development generally operates as a load-factoring facility when flow is not adequate to allow continuous operations. Generation occurs when there is sufficient water available for efficient use of one or both turbines. As a result, flows downstream from the powerhouse may fluctuate on an hourly basis, based on the amount of water available to the powerhouse. River flows in excess of powerhouse hydraulic capacity can allow continuous operation of the powerhouse. During cold weather, the plant generates power around the clock, not necessarily at peak efficiencies, to prevent freeze damage to the canal or equipment. The load-factoring operation allows commercial and recreational rafting opportunities from the powerhouse to Copco reservoir from May to mid-October. During that period, timing of flow releases may be determined in part by rafting use in the downstream reach.

The minimum flow requirement from J.C. Boyle dam established in the FERC license is 100 cfs. However, large springs a short distance below the dam supply an estimated additional 225 cfs of accretion flow, so actual minimum flows in most of the reach between the dam and the powerhouse are approximately 325 cfs or greater. River fluctuation downstream of the dam and the powerhouse is limited to a 9-inch-per-hour ramp rate, as measured at the U.S. Geological Survey (USGS) gage 0.25 mile downstream of the J.C. Boyle powerhouse and established in the existing FERC license (FPC 1956). Operating conditions can result in a fluctuation of about 3.5 feet between minimum and full pool elevations in the J.C. Boyle reservoir, but the average daily fluctuation is about 2 feet.

The Klamath River is free-flowing for about 22 miles from J.C. Boyle dam to Copco reservoir. The Copco No. 1 development consists of a reservoir, dam, and powerhouse located on the Klamath River between about RM 204 and RM 199 near the Oregon-California border. Generation at Copco No. 1 began in 1918. The impoundment formed upstream of the dam is approximately 1,000 surface acres containing about 40,000 acre-feet of total storage capacity and 6,235 acre-feet of active storage capacity. Copco No. 1 powerhouse is located at Copco dam.

Copco No. 1 operates for power generation, flood control, and control of water surface elevations of Copco and Iron Gate reservoirs. Like the J.C. Boyle development, Copco No. 1 generally operates as a load-factoring facility, usually from spring through summer and fall. Typical operation is to generate during the day when energy demands are highest and store water during non-peak times (weeknights and weekends). When river flows are near or in excess of turbine hydraulic capacity, the powerhouse generates continuously and excess water is spilled through spill gates. Copco reservoir can fluctuate 5.0 feet between normal minimum and full pool elevations, but the average daily fluctuation is about 0.5 foot. There are no specific requirements established for reservoir fluctuations.

The Copco No. 2 development consists of a diversion dam, small impoundment, and powerhouse located just downstream of Copco No. 1 dam between about RM 199 and RM 198. The reservoir created by the dam has minimal storage capacity (73 ac ft).

Copco No. 2 operation follows that of Copco No. 1. Water spills over the spillway crest when flows from Copco No. 1 exceed either the hydraulic capacity or the limited storage capacity of this facility. There are no "minimum instream flow" or "ramp rate" requirements for the relatively short (about 1.4 mile) downstream reach between Copco No. 2 dam and Iron Gate reservoir, but a flow of 5 to 10 cfs due to leakage and incidental releases is common. Water surface elevations of the reservoir rarely fluctuate more than several inches. No specific requirements have been established for reservoir fluctuations.

The Iron Gate development consists of a reservoir, dam, and powerhouse located on the Klamath River between about RM 197 and RM 190 about 20 miles northeast of Yreka, California. Iron Gate dam was completed in 1962 and is 173 feet high. The impoundment formed upstream of the dam is approximately 944 surface acres and contains about 50,000 ac ft of total storage capacity and approximately 3,790 acre-feet of active storage capacity. An ungated spillway 730 feet long leads to a large canal, allowing the transport of high flows past the structure. The powerhouse is located at the base of the dam.

The Iron Gate facility is operated for base load generation and to provide stable flows in the Klamath River downstream of the dam. It also provides the required minimum flows downstream of the facility. During periods of high flow, when storage is not possible, water in excess of generating capacity passes through the spillway.

FERC has stipulated minimum instream flow requirements to protect downstream aquatic resources as a condition of PacifiCorp's current Project license. FERC minimum flows are 1,300 cfs from September through April, 1,000 cfs in May and August, and 710 cfs in June and July. Since 1996, however, USBR's annual Project Operation Plans have dictated instream flow

releases. During that time, instream flow releases from Iron Gate dam, as required by USBR's annual project operation plans have generally exceeded the required FERC instream flows.

2.0 MODEL SELECTION

Flow and water quality conditions in the Klamath River basin vary dramatically along the approximately 250 river miles from Link dam (RM 254) near Klamath Falls Oregon to Turwar, California (RM 5), where the coastal estuary begins. There are a wide range of natural and anthropogenic influences affecting water quality along this long stretch of river. Significant influences on water quality in the system are induced by upstream inflows from hypereutrophic Upper Klamath Lake, the existence of four mainstem reservoirs, agricultural, municipal, and industrial discharges above Keno dam, and large tributary inflows in the lower reaches of the river.

Because of varying conditions along the river, and especially considering the very different hydrodynamics of steep river sections and reservoirs, different modeling systems were used to simulate river and reservoir reaches. River reaches were modeled with the Resource Management Associates (RMA) suite of finite-element hydrodynamic and water quality models. Reservoirs were modeled with U.S. Army Corps of Engineer's CE-QUAL-W2.

RMA models were chosen for river reaches because they are capable of accurately simulating flow and transport in steep river reaches. These models have been used historically on the Klamath River with good results (Deas and Orlob, 1999). The RMA suite includes RMA-2 and RMA-11, along with various utility programs. Flow is represented with RMA-2, a finite element hydrodynamic model capable of modeling highly dynamic flow regimes in short space- and time-steps. Output from this hydrodynamic model (including velocity, depth, and representative surface and bed areas) is passed to the water quality model RMA-11. RMA-11 is a finite element water quality model simulating the fate and transport of a wide range of physical, chemical, and biological constituents. These two linked river models are applied on hourly or sub-hourly time steps to capture the short-term response of state variables such as temperature and dissolved oxygen. For this application, the RMA models are applied in one-dimension, representing variations along the longitudinal axis of the river while averaging vertical and lateral details.

Reservoirs along the Klamath River are represented by the two-dimensional, longitudinal/ vertical hydrodynamic and water quality model CE-QUAL-W2. This model is produced and maintained by the US Army Corps of Engineers (USACE), and has also seen historic use on this river (ODEQ, 1995). Because the model assumes lateral homogeneity, it is well suited for reservoirs along the Klamath River, i.e., relatively long and narrow water bodies exhibiting longitudinal and vertical, but not strong lateral, water quality gradients. The CE-QUAL-W2 model is capable of representing a wide range of physical, chemical, and biological processes affecting water quality. The model can simulate selective withdrawal, sediment nutrient release dynamics, nitrogen inhibition under anoxic conditions, internal weirs and curtains, and other options useful in assessing a wide range of existing and possible future conditions of the system. To interface with the river model, time steps on the same scale as those of the river models have been employed.

For this application, the RMA water quality model (RMA-11) was modified to model labile organic matter. This modification allowed modeling results to be transferred easily from one model to the next so that the entire river could be reasonably modeled as one system. Details of

this modification to RMA-11 are presented in Appendix A. Other changes were made to both RMA-11 and to CE-QUAL-W2 to better represent river and reservoir water quality during the course of this study. Benthic algae concentrations in RMA-11, which have no limiting factors in the model, were given a maximum value to prevent excessive growth. To mimic its representation in CE-QUAL-W2, phytoplankton was given both respiration and mortality rates in RMA-11. Additional logic to assess topographic shading in river reaches was also implemented. Model simulations were completed in metric units, but are largely presented in English units herein, with the exception of water quality constituents.

3.0 MODEL IMPLEMENTATION

Model implementation required construction of appropriate system geometry, description of flow and water quality conditions, description of meteorological data, and definition of model parameters and constants. Flow and water quality conditions were described both initially throughout the system (initial conditions) and along the model's boundaries throughout the course of simulation (boundary conditions). After implementation, the model was calibrated and verified to observed data before being considered final and representative of the system.

- Geometry data includes a description of configuration (i.e., a set of points defined by latitude and longitude, UTM, or similar coordinate system), bed slope, and cross-section data. For reservoirs, bathymetric information and facilities information (such as stage-volume relationships, intake structure configurations, elevations, and locations of diversion structures and return points) are also included.

- Flow and water quality information includes system inflow (headwater, tributary, and return flows), outflow (diversions), reservoir storage change, and facilities operations. Water quality data for all inflows, as well as in-river and reservoir conditions, are also included.

- Meteorological data include standard parameters for heat budget calculation, e.g., air temperature, wet bulb temperature (or dew point temperature), solar radiation, cloud cover, wind speed, and/or barometric pressure.

- Other model parameters include selection of time step, spatial resolution, identified periods of analysis, and selection of default model constants and coefficients.

The current model has been through an external review (Wells, 2004) and modifications have been made to the original formulation. Detailed responses to the external review are provided in PacifiCorp (2005). PacifiCorp's modeling effort also has been an actively managed project wherein new information was incorporated into the framework as it became available. An example of this is the latest extension of the model to include calendar years 2002 through 2004.

3.1 RIVER-RESERVOIR REACHES (COMPONENTS OF KLAMATH RIVER MODEL)

The Klamath River Model represents the Klamath River as a series of river and reservoir reaches. In this configuration, each of the four mainstem reservoirs is modeled separately, as are each of the river sections that combine with them to comprise the entire river system. All together, there are eight distinct reaches of the river, four river reaches and four reservoirs, modeled separately but linked as one comprehensive model of the system. These eight distinct reaches are presented in Table 1 and shown on a map of the river in Figure 1.

Table 1. River Reaches and Representation in the Modeling Framework

Reach	Existing Representation	Model(s)
Link River	River	RMA-2/RMA-11
Lake Ewauna-Keno Dam	Reservoir	CE-QUAL-W2
Keno Dam to J.C. Boyle Reservoir	River	RMA-2/RMA-11
J.C. Boyle Reservoir	Reservoir	CE-QUAL-W2
Bypass-Peaking Reach[a]	River	RMA-2/RMA-11
Copco Reservoir[b]	Reservoir	CE-QUAL-W2
Iron Gate Reservoir	Reservoir	CE-QUAL-W2
IG Dam to Turwar	River	RMA-2/RMA-11

[a] The Bypass and Peaking sections are modeled as a single reach

[b] Copco 2 is not represented in the framework
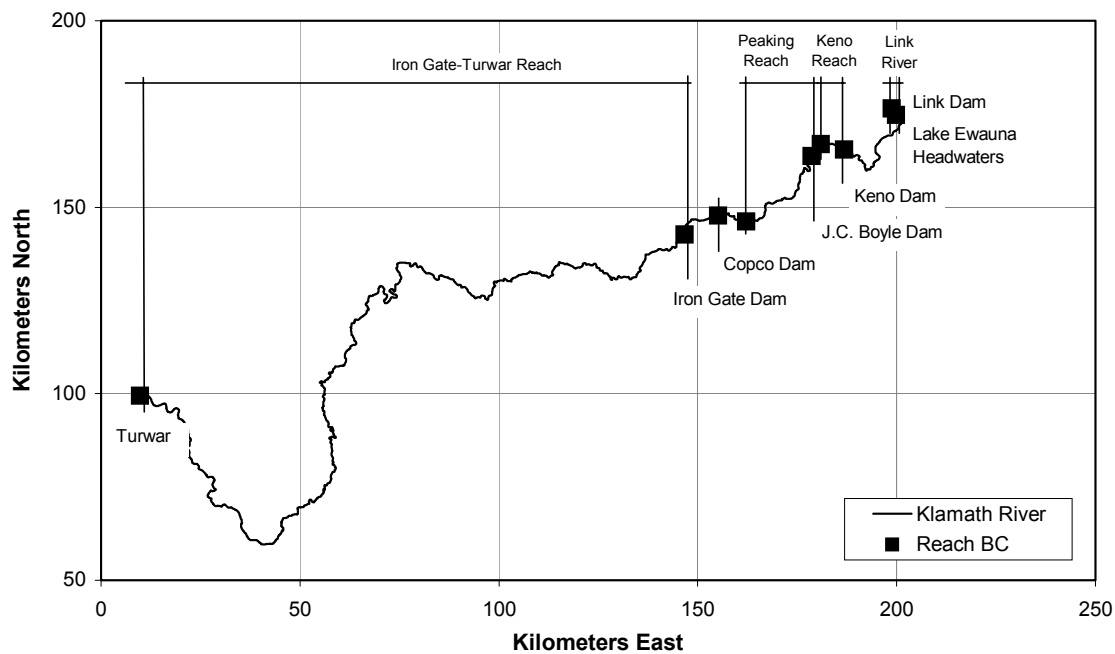
Figure 1. Designated River Reaches and Reservoirs

To create a systemwide simulation, the models are applied in series. Starting with the uppermost reach, Link River, flow and water quality are passed from one reach to the next. In other words, output from the Link River model forms the upstream boundary condition for the Lake Ewauna/ Keno reservoir model. Similarly, output from the Lake Ewauna/Keno reservoir model forms the headwater boundary condition for the model representing the Klamath River from Keno dam to J.C. Boyle dam (called the "Keno River" reach), and so on down the river.

Flow from the river hydrodynamics model RMA-2 is passed directly to CE-QUAL-W2, which models both hydrodynamics and water quality in the reservoir reaches. Likewise, flow from CE-QUAL-W2 is passed directly to RMA2. Most important water quality constituents are also passed directly between CE-QUAL-W2 and the river water-quality model RMA-11. These constituents, common to both models, include water temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), ammonia (NH_3), nitrate (NO_3), orthophosphate (PO_4), and phytoplankton algae. Values for other constituents are either assumed or derived. Details of these assumptions and derivations are given in the Boundary Conditions section of this report.

3.2 GEOMETRY

The numerical models used in this study require a detailed description of the system's physical characteristics. This description, the system "geometry," includes a map (i.e., a set of points given in latitude and longitude, UTM, or similar coordinate system that describes the system in plan view), bed slope, and cross-section data. For reservoirs, bathymetric information and facilities information (such as stage-volume relationships, intake structure locations, elevations, and locations of diversion structures and return points) are also required. In this section, the geometries of each river reach are presented and discussed.

Locations and orientations of river and reservoir reaches were determined from digitized versions of 1:24,000 USGS topographic quadrangles as discussed in Appendix B. Coordinates from these quadrangles were translated into a network of river nodes and elements and reservoir segments for use by the numerical models. All coordinates presented in this report are referenced to UTM 400000E 4500000N, NAD27 (typical).

Inflow can be represented in the geometry of an RMA reach in two ways. For inflows (e.g., tributaries) that form a large percentage of the base flow in the main stem, that inflow is represented as a small branch attached to the main stem with a junction. Junctions are placed at a single point, or node, in the model. For inflows to the main stem that are relatively modest, they may be represented as element side flows. An element side flow is distributed over the length of an element[1]. Both ways were used to represent inflows in the models used in this study as described in the reach-specific descriptions below.

3.2.1 Link River Reach

The Link River reach starts at Link dam (RM 254) and terminates 1.3 miles downstream at Lake Ewauna (RM 253). The Link River reach is simulated with two junctions, representing separate powerhouse discharges into the reach, and no element side flows. Link River Reach geometry is summarized in Table 2. The Link River reach and important locations within the reach are shown in Figure 2 and presented in Table 3. This reach is modeled with the RMA-2 and RMA-11 models.

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[1] For more information on nodes and elements refer to RMA-2 model documentation (King, 2001).

Table 2. Link River Reach Geometry Summary

Node spacing	75 meters
Number of nodes	29 nodes in length; 37 nodes total including junctions
Length	1.31 miles from RM 252.57-253.88
Elevations	Range: 1245-1259 meters
Widths	Constant widths: 5 meters main stem; 20 meters junction elements
Side slopes	20:1 main stem; 1:1 junctions
Data sources	UTM coordinates from CH2M HILL; Elevations estimated from USGS topographic maps
Notes	2 junctions: East side, West side; Nodes 30-33 at East side; 34-37 at West side
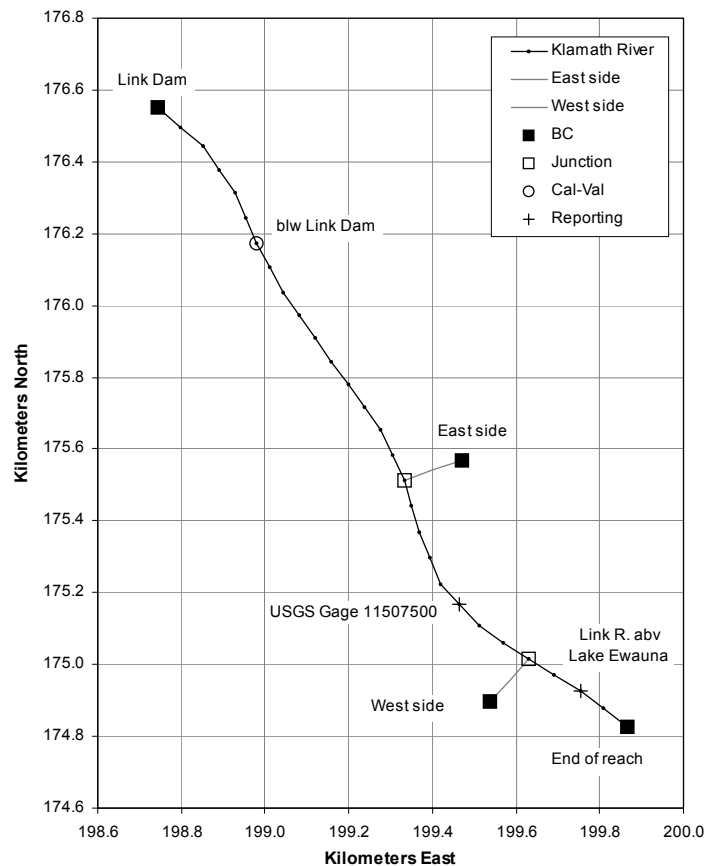
Figure 2. Map of Link River Representation

Table 3. Geometry Information for Link River

Location	Node	Element	x-coord	y-coord	Site type
Link Dam	1	1	198.8	176.6	BC
East Side	17	9	199.9	174.8	BC
West Side	25	13	199.5	175.6	BC
End Link R reach	29	14	199.5	174.9	BC
East Side	30	15	199.3	175.5	Junction, inflow
West Side	34	16	199.6	175.0	Junction, inflow
USGS Gage 11507500	22	-	199.5	175.2	Reporting Point
Link River above Lake Ewauna	27	-	199.8	174.9	Reporting Point

3.2.1.1 Bed Elevations/Slope

Bed slope for the Link River reach was estimated from USGS topographic maps and assumed Lake Ewauna elevations. Elevations were estimated from topographic contours to preserve the general slope of the river. Upstream reach elevation was set at 4131 ft (1259 m) MSL and downstream reach elevation was set at 4085 ft (1245 m) MSL.

3.2.1.2 Cross-sections

Link River widths were obtained from 1:7,500-scale aerial photos taken July 21, 1988. Daily average flow for that day was 920 cfs. For numerical stability in this short and steep reach, bottom width of the main stem was set to a constant 5 meters. These widths were assumed to represent bottom widths of trapezoidal cross-sections with twenty-to-one side slopes on the main stem and one-to-one side slopes in tributaries.

3.2.2 Lake Ewauna-Keno Reservoir

The Lake Ewauna to Keno dam reach extends from the headwaters of Lake Ewauna (RM 253) 20 miles downstream to Keno dam (RM 233). The impoundment (i.e., Keno reservoir) is generally a broad, shallow body of water. Widths range from several hundred to over 1,000 feet (a range of about 90 to 300 meters), and depths range to a maximum of roughly 20 feet (approximately 6 meters). A total of 18 discharges and 7 withdrawals were represented in the model. This reach is modeled with CE-QUAL-W2.

3.2.2.1 Keno Dam Features

The Keno dam spillway, with an invert elevation of 4,070 feet, contains six Taintor gates. Three additional outlets include a sluice conduit, the fish attraction outlet, and a fish ladder. Details of these outlets are summarized in Table 4.

Table 4. Keno Dam Outlet Features

Outlet	Invert Elevation	Dimension	Operation
Sluice Conduit	4,073.0 ft	36 inch diameter	Manual gate
Fish Attraction Outlet	4,075.0 ft	30 inch diameter	Manual gate
Fish Ladder	4,078.5 ft	60 inch width	Stop logs
Spillway	4,070.0 ft	6 gates @ 40 ft width each	Remote control on three gates

Sources: PacifiCorp (2002), PacifiCorp (2000)
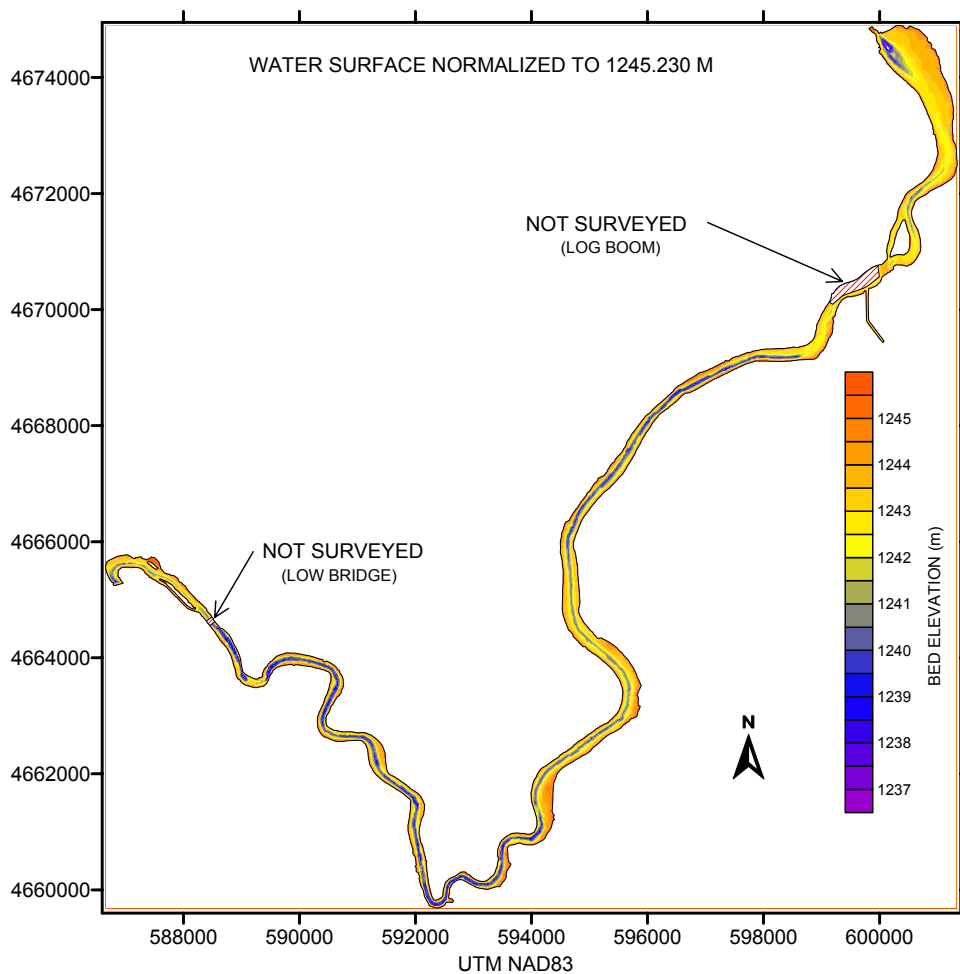
Figure 3. Keno Reservoir Bathymetry (PacifiCorp, 2004a)

3.2.2.2 Reservoir Bathymetry

The Lake Ewauna to Keno dam model was originally implemented with bathymetry derived from an earlier model of this reach created by Wells (ODEQ, 1995). This original representation was replaced with data from a recent bathymetric survey of the entire reservoir (PacifiCorp, 2004a) (Figure 3).

The number of segments, number of layers, segment lengths, layer widths per segment and water surface elevation were largely retained from the previous CE-QUAL-W2 modeling of the reach by ODEQ (1995), but were supplemented with new segment orientations calculated from x-y coordinates obtained from digitized versions of 1:24,000 USGS topographic quadrangles. River segment orientations were updated because the original orientations (ODEQ 1995) contained discrepancies when applied to the newer versions of CE-QUAL-W2 used in this study. Model representation of this reach is shown in Figure 4.
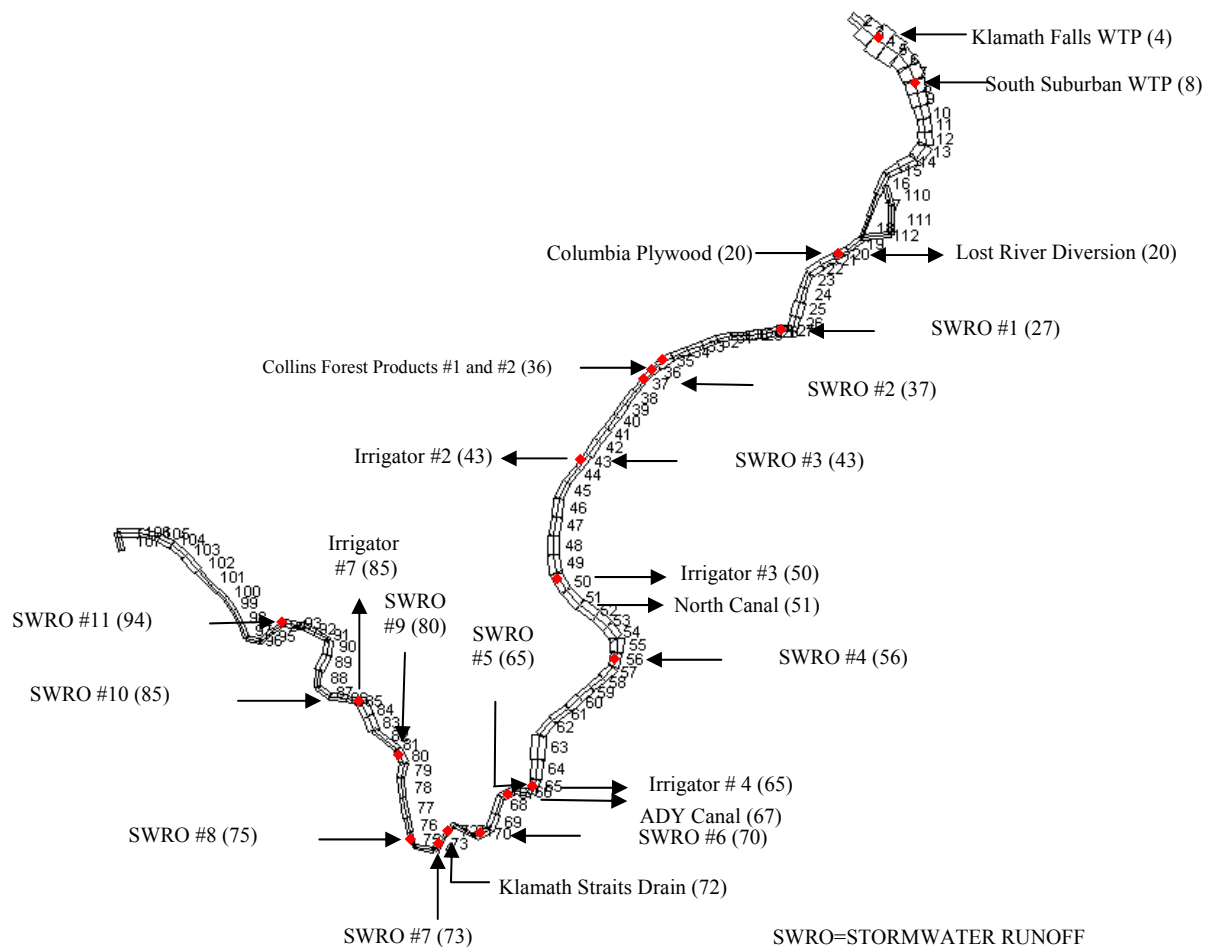
Figure 4. Map of Lake Ewauna to Keno Dam CE-QUAL-W2 Representation, Identifying Inputs and Withdrawals

The CE-QUAL-W2 representation of Lake Ewauna to Keno dam reach consists of two connected reservoir sections, or branches. The main branch, Branch 1, spans the entire length of the reach and is comprised of 106 active segments, all 1,000 ft (304.8 m) in length. A second,

smaller branch, Branch 2, provides an alternate flow path from segment 14 to segment 18 of Branch 1. Branch 2 has no external inflows or outflow and is comprised of three active segments, each 800 ft (243.8 m) in length. A total of 18 discharges and 7 withdrawals were represented in the model (see Table 5). The 15 active layers of this reach are all 2.00 ft (0.61 m) thick. Total volume generated by this model representation was consistent with volume calculated from reservoir bathymetry available from PacifiCorp. Simulated and observed stage-volume curves are shown in Figure 5.

Table 5. Modeled Inflows and Outflows in the Lake Ewauna to Keno Dam Reach

Name	Type	River Bank [a]	Approximate RM [b]	Model Segment
Klamath Falls Wastewater Treatment Plant	Inflow	Left	253	4
South Suburban Sanitation District	Inflow	Left	252	8
Columbia Plywood	Inflow	Right	250	20
Lost River Diversion	Inflow/Outflow	Left	250	20
Collins Forest Products #1	Inflow	Right	247	36
Collins Forest Products #2	Inflow	Right	247	36
Klamath Straits Drain	Inflow	Left	240	72
Stormwater Runoff #1	Inflow	NA	249	27
Stormwater Runoff #2	Inflow	NA	247	37
Stormwater Runoff #3	Inflow	NA	246	43
Stormwater Runoff #4	Inflow	NA	243	56
Stormwater Runoff #5	Inflow	NA	242	65
Stormwater Runoff #6	Inflow	NA	241	70
Stormwater Runoff #7	Inflow	NA	240	73
Stormwater Runoff #8	Inflow	NA	240	75
Stormwater Runoff #9	Inflow	NA	239	80
Stormwater Runoff #10	Inflow	NA	238	85
Stormwater Runoff #11	Inflow	NA	236	94
North Canal	Outflow	Left	247	35
ADY Canal	Outflow	Left	241	67
Irrigator #2 [c]	Inflow/Outflow	NA	246	43
Irrigator #3 [c]	Inflow/Outflow	NA	244	50
Irrigator #4 [c]	Inflow/Outflow	NA	242	65
Irrigator #7 [c]	Inflow/Outflow	NA	238	85

[a] River bank is given for reference only. The model does not discriminate between banks when simulating flows.

[b] River miles are approximate as each model segment is 1000 ft in length.

[c] Nomenclature after Wells (ODEQ, 1995)

Placement of stormwater runoff and irrigator flows is as per ODEQ (1995).
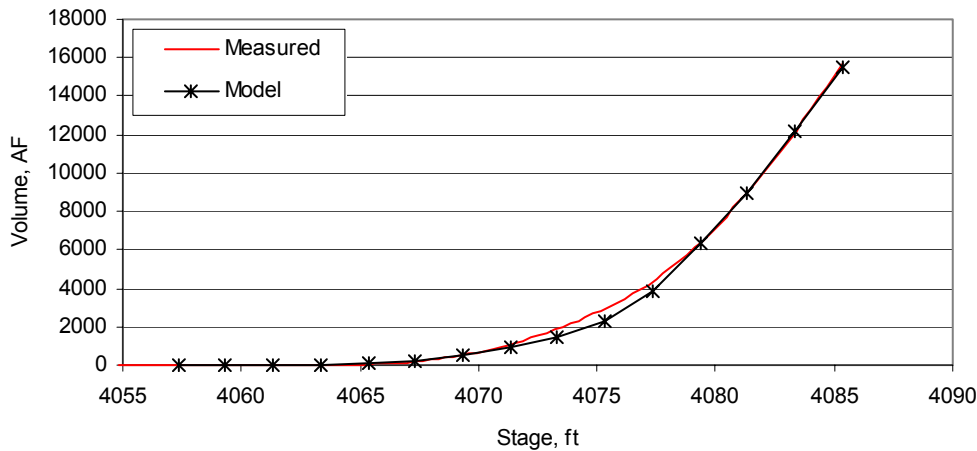
Figure 5. Comparison of Measured and Model Representation of Lake Ewauna Stage-Volume (S-V) Relationships

3.2.3 Klamath River from Keno Dam to J.C. Boyle Reservoir Reach

The Keno reach extends 5.4 miles from Keno dam (RM 233) downstream to the headwaters of J.C. Boyle reservoir (RM 227). No appreciable tributary inflows occur in this reach. Key locations in the Keno reach are presented in Table 6 and a model representation of the reach is shown in Figure 6. This reach is modeled with the RMA models.

Table 6. Klamath River, Keno Reach Geometry Information for the RMA-2 and RMA-11 Models

Location	Node	Element	x-coord	y-coord	Site type
Keno Dam	1	1	186.8	165.4	BC, upper
End Keno R reach	117	58	181.0	166.9	BC, lower
A/D Keno reach	73	37	183.7	167.0	A/D
1/4 mi abv J.C. Boyle	110	56	181.4	166.9	Cal/Val and Reporting

BC – boundary condition (flow, constituent concentration, stage)

A/D – accretion/depletion location

Reporting – model output location
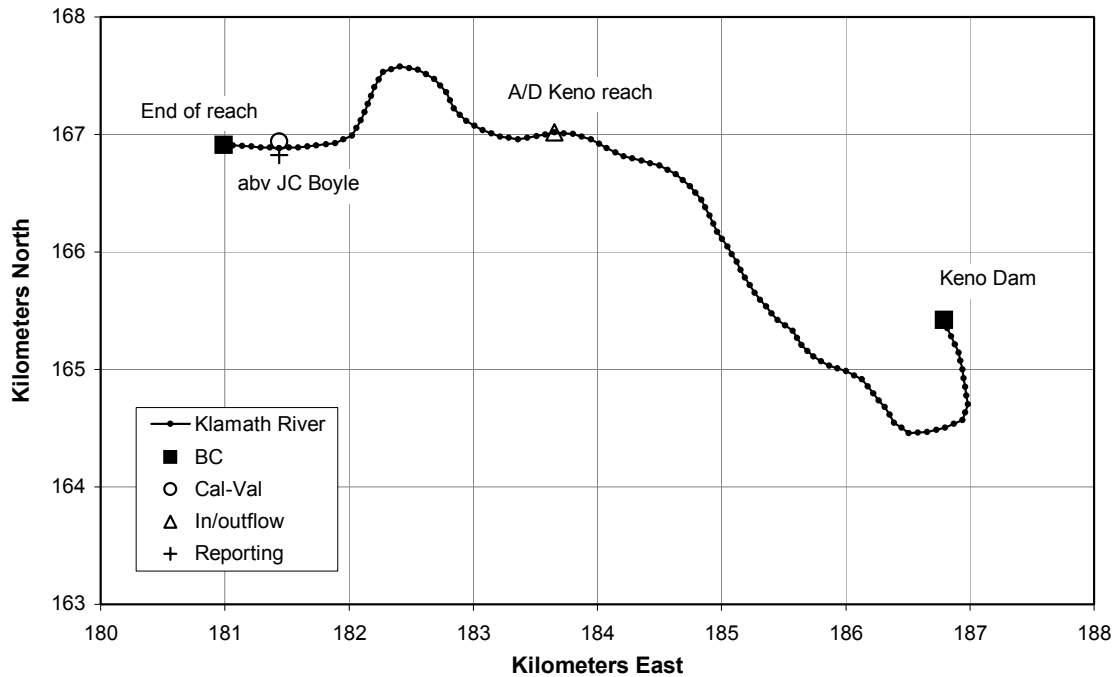
Figure 6. Klamath River, Keno Reach Representation

3.2.3.1 Bed Elevation/Slope

Bed slope for the Keno reach was estimated from USGS topographic maps, known elevations at Keno Dam, and estimated water surface elevations downstream in J.C. Boyle reservoir. Estimated reach elevations range from approximately 3796 ft (1158 m) MSL to 4019 ft (1225 m) MSL.

3.2.3.2 Cross-sections

Keno reach widths were obtained from habitat surveys conducted by Thomas R. Payne and Associates (TRPA) (PacifiCorp, 2004b). Measurements were completed at roughly eight locations per mile. Because measurement locations did not always coincide with the x-y coordinates of the model, field data were linearly interpolated to determine widths for model cross sections. Extreme variations in measured widths were smoothed with a seven-times running average to produce estimates of bottom width. Using these estimates of bottom width, trapezoidal river cross-sections were constructed for each node of the reach at evenly spaced intervals of 75 meters, assuming 1:1 side slopes. A summary of Keno reach geometry is given in Table 7.

Table 7. Klamath River, Keno Reach Geometry Summary

Node spacing	75 meters
Number of nodes	117 nodes in length
Length	5.37 miles from RM 228.69-234.06
Elevations	Range: 1158-1225 meters
Widths	Range: 28-78 meters
Side slopes	1:1
Data sources	UTM coordinates from CH2M HILL; Elevations estimated from USGS topographic maps
Notes	n/a

3.2.4 J.C. Boyle Reservoir

The J.C. Boyle reservoir reach extends 3.3 miles from the headwaters of J.C. Boyle reservoir (RM 228) to J.C. Boyle dam (RM 224). This reservoir primarily serves to regulate flows for the J.C. Boyle powerhouse located downstream at RM 220. The one significant tributary to this reach, Spencer Creek, is represented in the model as inflow added to Klamath River inflows at the headwater of the reservoir.

3.2.4.1 J.C. Boyle Dam Features

J.C. Boyle dam has four primary outlets: a spillway, a fish ladder, and two outlets into the waterway intake (a fish screen bypass and a waterway pipeline). Details of operational outlets are summarized in Table 8. This reach is modeled with CE-QUAL-W2.

Table 8. J.C. Boyle Dam Outlet Features

Outlet	Invert Elevation	Dimension	Operation
Fish ladder	3780.0 ft	24 inch diameter	Manual
Fish Screen Bypass	3757.0 ft	24 inch diameter	Manual
Waterway pipeline	3775.0 ft	14 foot diameter	**
Spillway	3782.0 ft	3 radial gates @ 35 ft width each	Remote control on one gate

Sources: PacifiCorp (2002), PacifiCorp (2000), PacifiCorp drawing: Exhibit L-4

3.2.4.2 Reservoir Bathymetry

Unlike the Lake Ewauna to Keno dam reach, J.C. Boyle reservoir has never been modeled with CE-QUAL-W2. Reservoir geometry was derived from bathymetric data (PacifiCorp, 2004a) and is presented in Figure 7. Segment length, segment orientation, layer thickness and width were required for the reservoir model. Based on the variation in the reservoir morphology and widths, the reservoir was divided into 20 active segments 887 ft (270m) in length. Segments were chosen to capture both the general shape of J.C. Boyle reservoir and pertinent features (Figure 8).
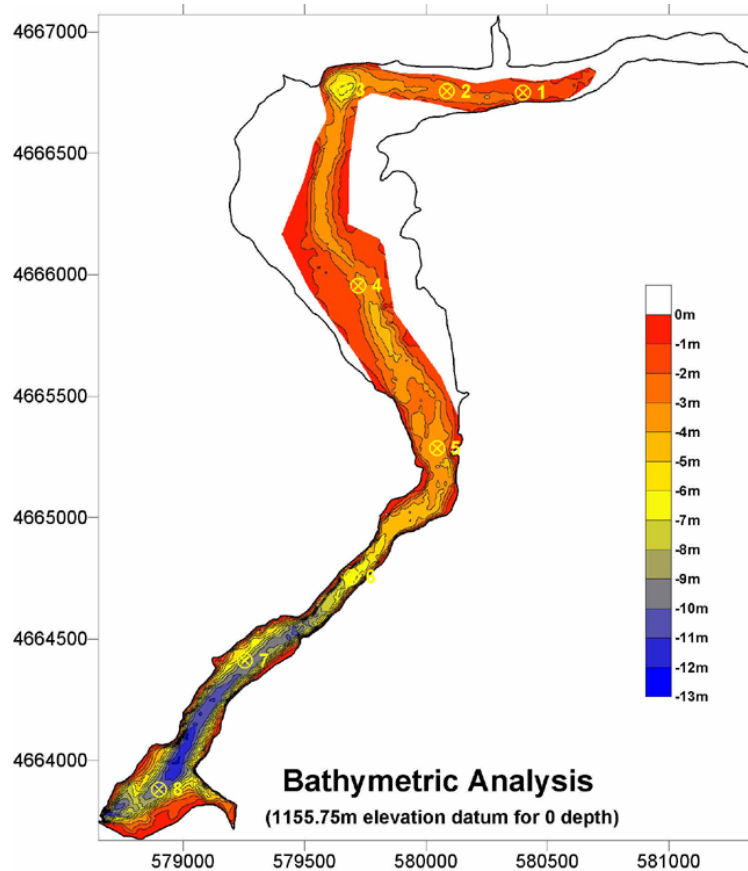
Figure 7. J.C. Boyle Reservoir Bathymetry (PacifiCorp, 2004a)

Layer thickness was set to 3.28 feet (1.0 meter). Layer widths were determined from cross-sectional information taken at the middle of each segment. Twelve active layers of varying widths were determined for each segment from this method. Although a representation using finer resolution (i.e., smaller layer thickness less than 1 meter) was attempted, models using these refined cross-sections took an uncommonly long time (on the order of a day) to run for each one-year simulation period). The model was continually adding and subtracting both layers and segments to account for the dynamic water surface elevations imposed by hydropower operations. A layer thickness of 1 meter produced reasonable results, and one-year simulation times were appreciably reduced to approximately 10 minutes.

A stage-volume curve was generated from the bathymetry data and compared to the measured stage-volume curve of the reservoir. Modeled and measured stage-volume relationships are compared in Figure 9.
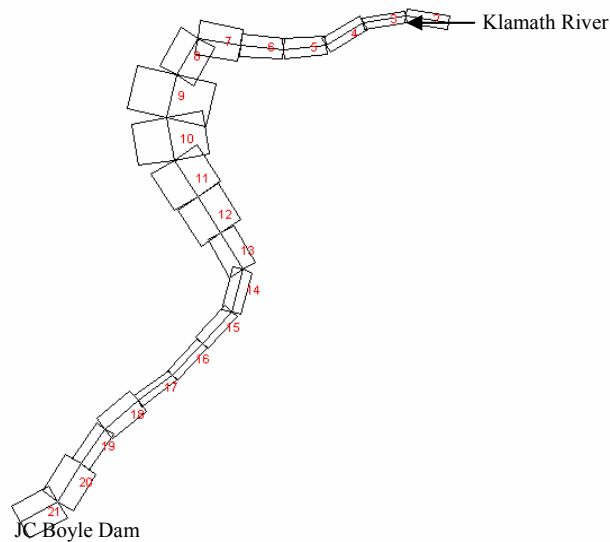
Figure 8. Representation of J.C. Boyle Reservoir in CE-QUAL-W2
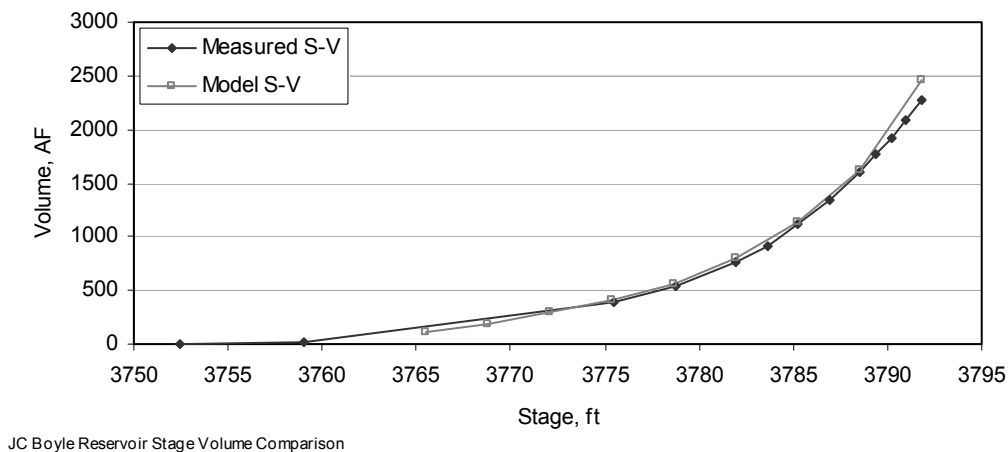
Figure 9. Comparison of Measured and Model Representation of J.C. Boyle Reservoir Stage-Volume (S-V) Relationships

3.2.5 J.C. Boyle Bypass and Peaking Reaches

The J.C. Boyle bypass and peaking reaches extend 20.8 miles from J.C. Boyle dam (RM 224) to the headwaters of Copco reservoir (RM 204). Noteworthy features of the reaches include diversion of mainstem flows at J.C. Boyle dam for hydropower production, the powerhouse penstock return marking the beginning of the peaking reach roughly 4 miles downstream from J.C. Boyle dam (RM 220), a large springs complex in the bypass reach, and hydropower peaking operations downstream of the powerhouse. A few small streams enter the reach, the most significant of which is Shovel Creek. The reaches are shown in Figure 10. Important locations within the bypass and peaking reaches are presented in Table 9. These reaches are modeled with the RMA models.
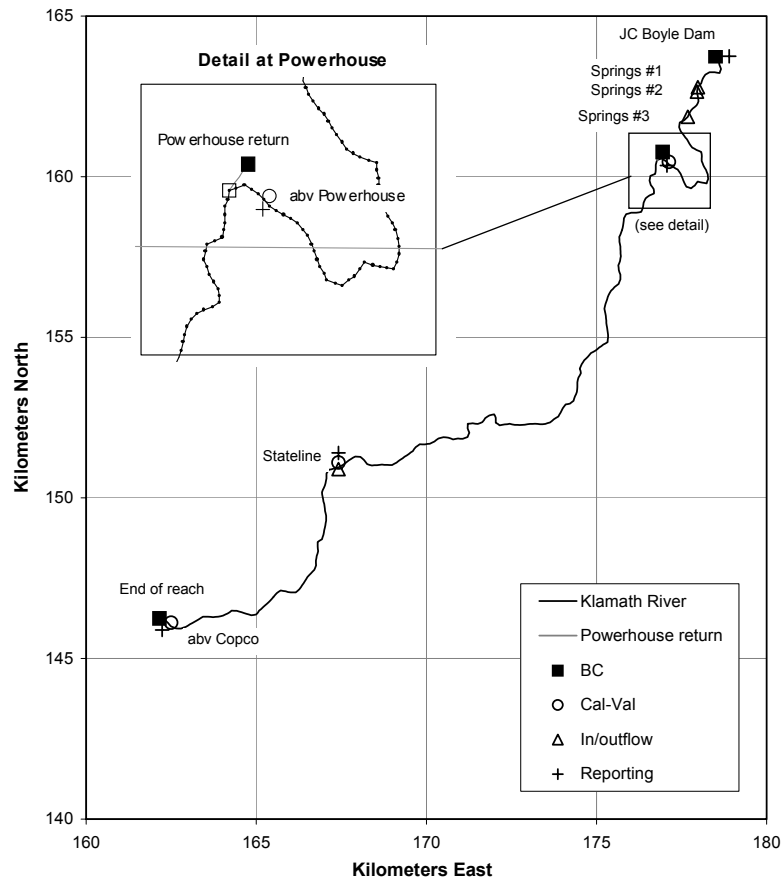
Figure 10. J.C. Boyle Bypass and Peaking Reach Representation

Table 9. Geometry Information for J.C. Boyle Bypass and Peaking Reach EC Simulation

Location	Node	Element	x-coord	y-coord	Site type
J.C. Boyle Dam	1	1	178.7	163.7	BC, upper
End Peaking reach	453	226	162.2	146.2	BC, lower
J.C. Boyle Powerhouse	95	48	176.9	160.8	BC
Simulated Powerhouse Return	97	49	176.8	160.5	Junction, inflow
1/4 mi abv Powerhouse	91	46	177.1	160.4	Cal-Val
1/4 mi abv Shovel Cr	389	195	166.3	147.2	Cal-Val
1/4 mi abv Copco	447	224	162.5	146.00	Cal-Val
CA-OR Stateline	331	166	167.4	151.1	Cal-Val, A/D
Springs #1	21	11	178.0	162.8	A/D
Springs #2	23	12	178.0	162.6	A/D
Springs #4	35	18	177.7	161.9	A/D

BC – boundary condition

A/D – accretion/depletion location

Cal-Val – calibration and validation location

3.2.5.1 Bed Elevation/Slope

Bed slope for these reaches was estimated from USGS topographic maps and reported elevations at J.C. Boyle dam and Copco reservoir water surface elevations. Reach elevations range from approximately 2592 ft (790 m) MSL to 3760 ft (1146 m) MSL.

3.2.5.2 Cross-sections

J.C. Boyle bypass and peaking reach widths were obtained from habitat surveys completed by TRPA (PacifiCorp, 2004b). Measurements were completed at roughly eight locations per mile. Because measurement locations did not always coincide with the 1:24,000 x-y coordinates of the model, field data were linearly interpolated to provide widths for cross-sections of the model. Extreme variations in measured widths were smoothed with a seven-times running average to produce estimates of bottom width. Using these estimates of bottom width, trapezoidal river cross-sections were constructed for each node of the reach at evenly spaced intervals of 75 meters, assuming 1:1 side slopes. Widths and other geometric characteristics of the bypass and peaking reaches are summarized in Table 10.

Table 10. J.C. Boyle Bypass and Peaking Reach Geometry Summary

Node spacing	75 meters
Number of nodes	459 nodes in length
Length	20.81 miles from RM 204.72-225.53
Elevations	Range: 790-1146 meters
Widths	Range: 12-66 meters
Side slopes	1:1
Data sources	UTM coordinates from CH2M HILL; Elevations estimated from USGS topographic maps
Notes	1 junction: J.C.B Powerhouse; Nodes 97, 458, 459

3.2.6 Copco Reservoir

The Copco reservoir reach extends 5.0 miles from Copco reservoir headwaters (RM 204) downstream to Copco dam (RM 199). No tributaries are represented in this section of the model. Physical data for the Copco reservoir model are outlined below. This reach is modeled with CE-QUAL-W2.

3.2.6.1 Copco Dam Features

Copco dam has three primary outlets: a spillway and two penstocks that provide flows to the Copco No. 1 powerhouse. The two penstocks, fed by three intakes, are treated as a single outlet with an average centerline elevation of 2,581 feet. Details of these outlets are summarized in Table 11. Because of the close proximity and similar invert elevations, the outlet works were represented in the reservoir as a single withdrawal with a midline elevation of 2,581 ft (786.6 m).

Table 11. Copco Dam Outlet Features

Outlet	Invert Elevation	Dimension	Operation
Penstock Intake (Unit 1)	2575 ft	Two intakes @ 10-foot diameter each	Remote Operation
Penstock Intake (Unit 2)	2575 ft	14 foot diameter	Remote Operation
Spillway	2594 ft	3 radial gates @ 35 ft width each	Remote control on one gate, others by motorized hoist

Sources: PacifiCorp (2002), PacifiCorp (2000)

3.2.6.2 Reservoir Bathymetry

Copco reservoir geometry, shown in

Figure 11, was derived from bathymetric data of Copco reservoir (PacifiCorp, 2004a). Segment length, segment orientation, layer thickness and width were required for the reservoir model. Segments were identified based on changes in reservoir morphology and widths. The reservoir was divided into 17 active segments 1,329 ft (405.4 m) in length. Segments were chosen to capture both the general shape of Copco reservoir and pertinent features, such as the submerged features near the dam. Due to the large bedrock outcrop in the vicinity of the Copco dam, a submerged weir was implemented in the model from layer 20 to 32.
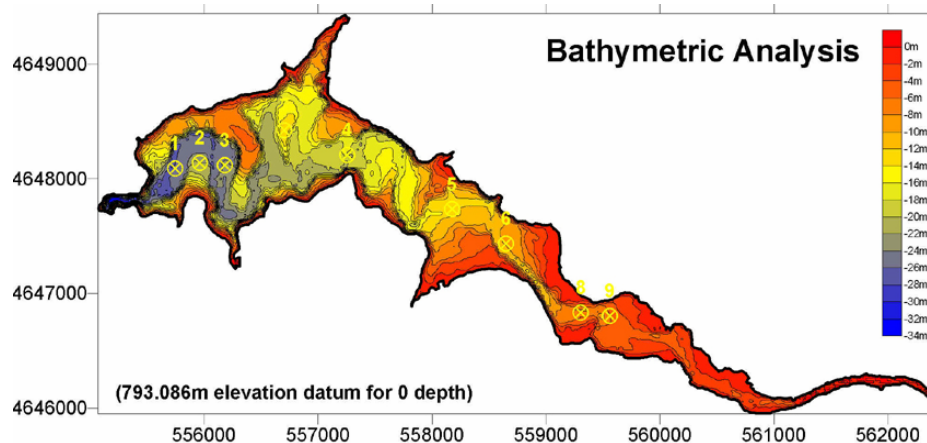
Figure 11. Copco Reservoir Bathymetry (PacifiCorp, 2004a)

Layer thickness was set to 3.28 ft (1.0 m). Layer widths were determined from cross-sectional information taken at the middle of each segment. Thirty-two active layers of varying widths were determined for each segment from this method. The 3.28 ft (1.0 m) layer thickness produced reasonable results and resulted in reasonable execution times. One-year simulation times were approximately 15 minutes. Final CE-QUAL-W2 representation of Copco reservoir is shown in Figure 12.
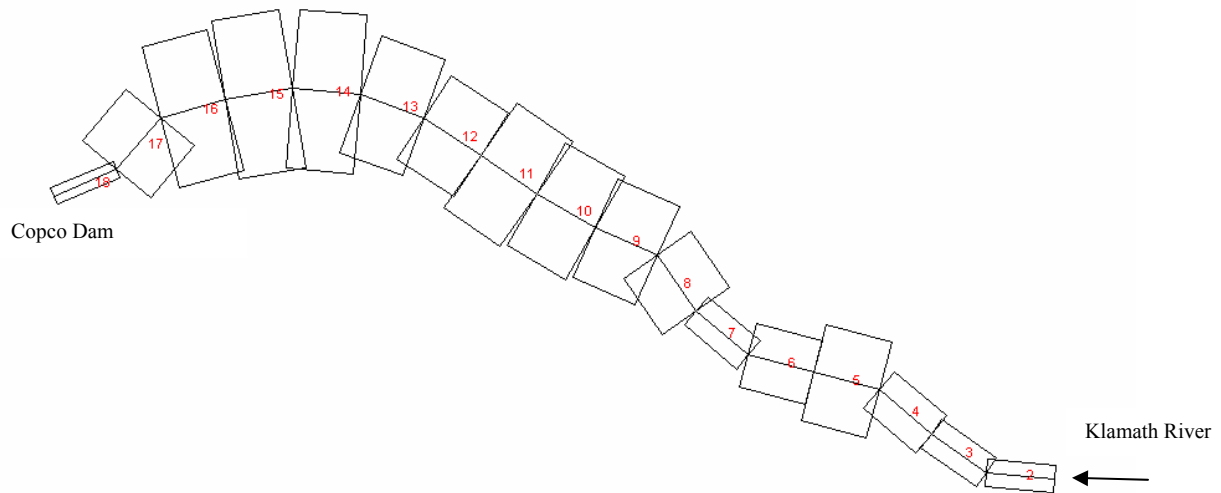
Figure 12. Representation of Copco Reservoir in CE-QUAL-W2

A stage-volume curve was generated by the model and compared to the measured stage-volume curve of the reservoir to ensure proper volume and storage representation. Modeled versus measured stage-volume relationships are compared in Figure 13.

Copco Reservoir Stage Volume Comparison
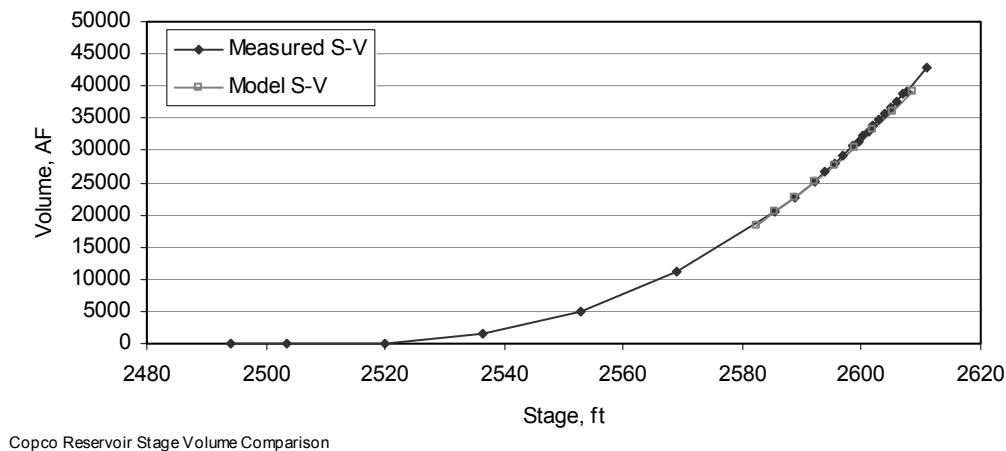
Figure 13. Comparison of Measured and Model Representation of Copco Reservoir Stage-Volume (S-V) Relationships

3.2.7 Iron Gate Reservoir

Iron Gate reservoir extends 6.4 miles from the headwaters of Iron Gate reservoir (RM 197) to Iron Gate dam (RM 190). Except in "Without Project" scenarios, the small Copco #2 Reservoir and short river reach between Copco and Iron Gate reservoirs are not represented in the model.

Instead, Copco reservoir runs directly into Iron Gate reservoir. Three tributaries to Iron Gate reservoir are represented in this CE-QUAL-W2 model: Camp Creek, Jenny Creek, and Fall Creek. The spillway for the dam is modeled as a withdrawal in the last active segment because the spillway structure draws water to the side of the dam, not over or through the dam itself. Due to its dendritic shape, Iron Gate reservoir is represented by two branches, including a main branch that receives water released from Copco Reservoir and a Camp Creek branch that represents a sizeable arm of the reservoir running up to Camp Creek. Geometry of the reservoir is outlined below.

3.2.7.1 Iron Gate Dam Features

Iron Gate dam has four primary outlets: a spillway, a penstock, and two outlets that supply fish hatchery intakes. The details of these outlets are summarized in Table 12.

Table 12. Iron Gate Dam Outlet Features

Outlet	Invert Elevation	Dimension	Operation
Upper Fish Hatchery	2293 ft	24 inch diameter	Manual
Penstock Intake	2309 ft	12 foot diameter	Remote operation
Lower Fish Hatchery	2253 ft	24 inch diameter	Manual
Spillway	2328 ft	Side channel (727 feet in length)	Overflow

Sources: PacifiCorp (2002), PacifiCorp (2000)

3.2.7.2 Reservoir Bathymetry

Reservoir geometry was derived from bathymetric data of Iron Gate reservoir (PacifiCorp, 2004a). Reservoir bathymetry is depicted in Figure 14. Segments were laid out on the basis of changes in reservoir orientation and width. The main branch, Branch 1, has 30 active segments and the Camp Creek Branch, Branch 2, has five active segments. Segment lengths were 1,204 ft (367 m), with the exception of the narrows near the upper end of the reservoir, where half element lengths were used. Branch 2 has an external upstream boundary (Camp Creek) and connects with Branch 1, Segment 23. A schematic of model layout is presented in Figure 15, showing model segments and tributary flows.
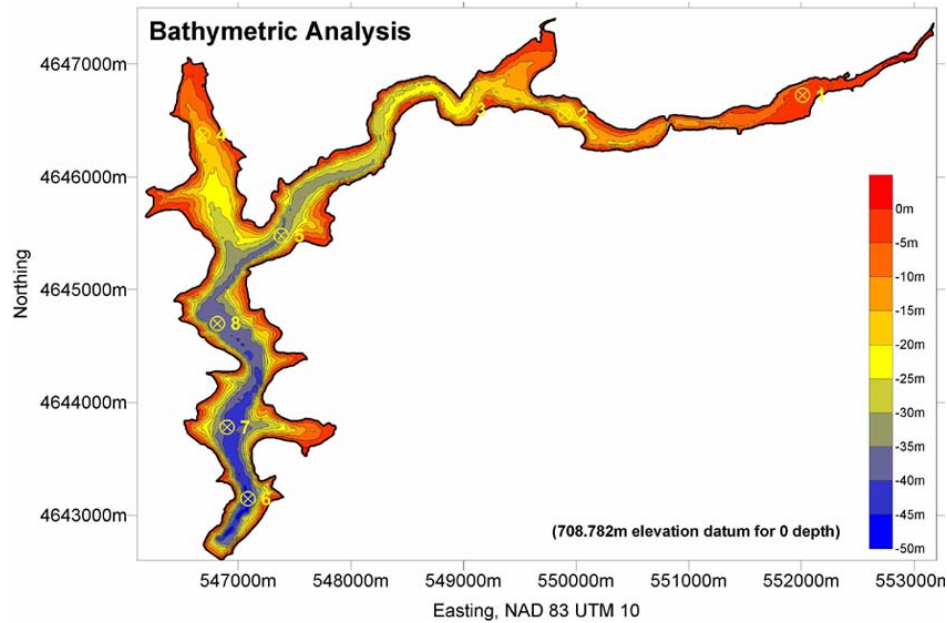
Figure 14. Iron Gate Bathymetry (PacifiCorp, 2004a)

Based on cross-sectional information from the mid-point of each segment, Iron Gate Reservoir is represented by 50 active layers, each 3.28 ft (1 m) in thickness. Modeled and measured stage-volume curves are compared in Figure 16.
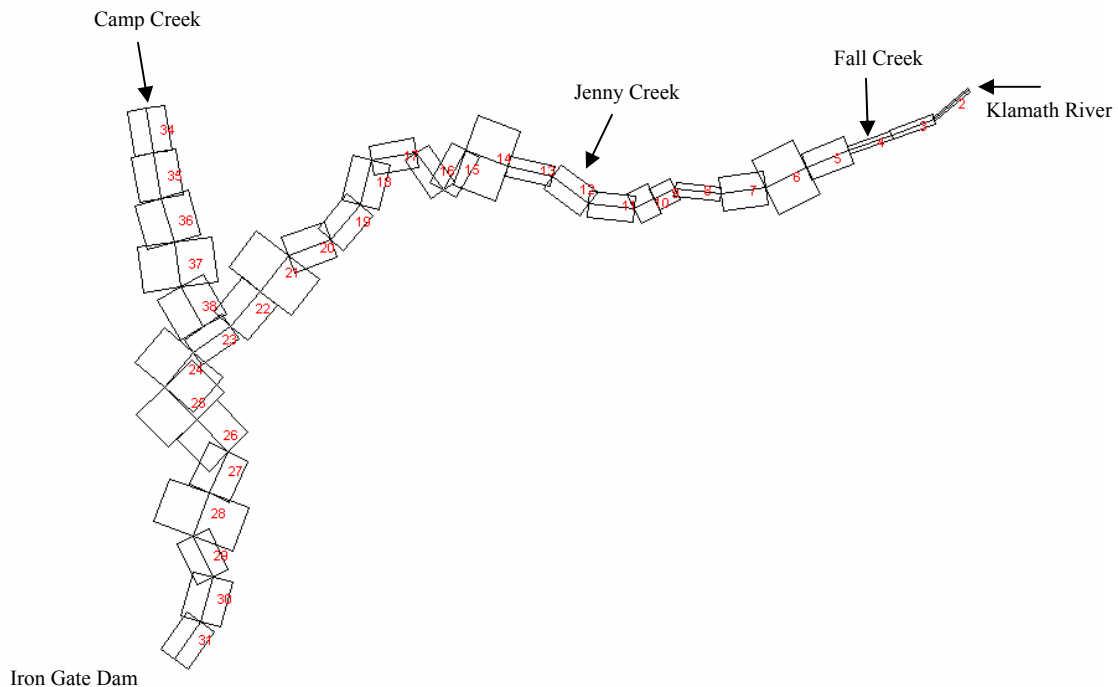
Figure 15. Representation of Iron Gate Reservoir for CE-QUAL-W2

Irongate Reservoir Stage Volume Comparison
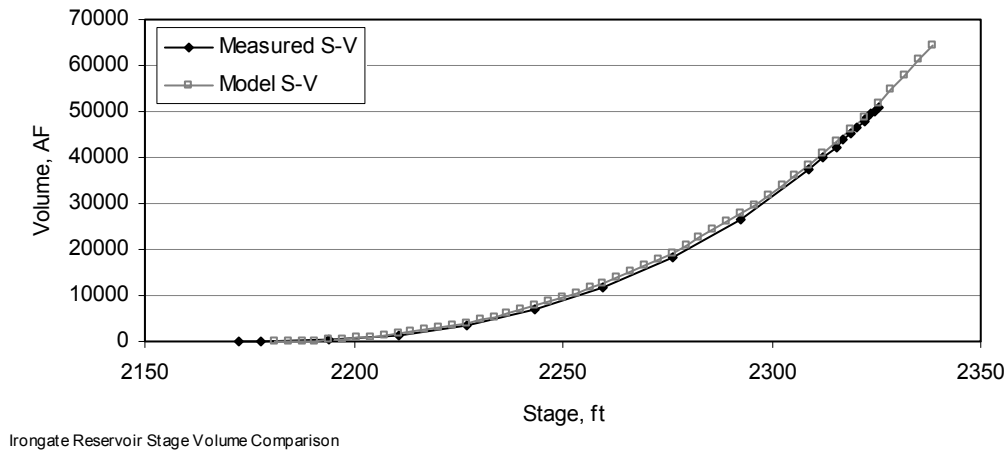
Figure 16. Comparison of Measured and Model Representation of Iron Gate Reservoir Stage-Volume (S-V) Relationships

3.2.8 Iron Gate to Turwar Reach

The Iron Gate dam to Turwar reach extends 185 miles from Iron Gate dam (RM 190) to Turwar near the mouth of the Klamath River (RM 5). Several main tributaries flow into the reach: Shasta River, Scott River, Salmon River, and Trinity River. Many smaller creeks contribute significant flow to the river along this reach and these creeks are also included in the simulation. Geometry of this reach is outlined below.

3.2.8.1 Map Coordinates

X-y coordinates describing the course of the river were taken from a digitized version of the 1:24,000 USGS topographic quadrangles, as discussed in Appendix B. This information was translated into a series of nodes and elements for use by the numerical model. The model network is shown with simulated tributaries in Figure 17. Important locations within the reach, including tributaries and output locations, are presented in Table 13. Nodal spacing for the numerical grid was roughly 490 feet (150 meters). Sensitivity analyses showed model results to be relatively insensitive to a reduction in grid spacing.
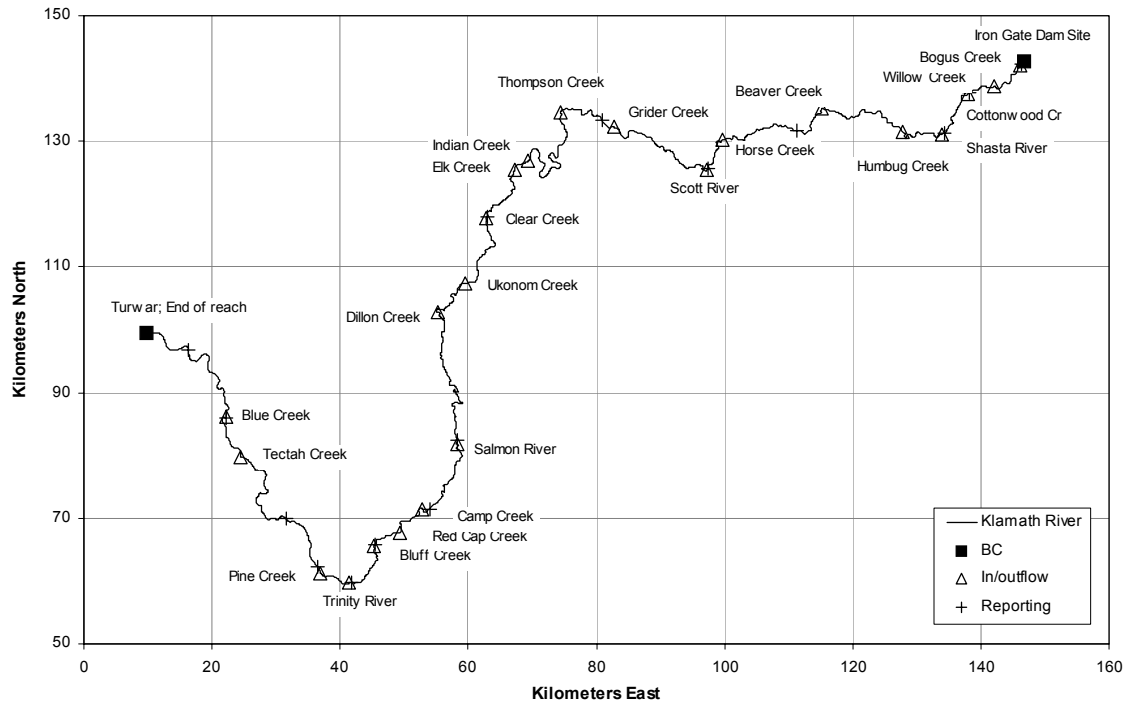
Figure 17. Iron Gate Dam to Turwar Reach Representation Showing Tributary Names

Table 13. Geometry Information for the IG-Turwar reach (150-meter grid)

Location	Node	Element	x-coord	y-coord	Site Type
Iron Gate Dam	1	1	146.747	142.634	BC, upper
End IG-Turwar reach	2081	1040	9.821	99.506	BC, lower
Bogus Creek	7	4	146.141	142.022	A/D
Willow Creek	55	28	142.035	138.739	A/D
Cottonwood Creek	86	43	137.904	137.535	A/D
Shasta River	144	72	133.963	131.178	A/D
Humbug Creek	204	102	127.848	131.402	A/D
Beaver Creek	319	160	115.190	135.232	A/D
Horse Creek	468	234	99.597	130.180	A/D
Scott River	513	257	97.299	125.428	A/D
Grider Creek (A/D Scott to Seiad)	656	328	82.714	132.246	A/D
Thompson Creek	735	368	74.440	134.626	A/D
Indian Creek	906	453	69.371	126.831	A/D
Elk Creek	925	463	67.209	125.507	A/D
Clear Creek	1000	500	62.733	117.818	A/D
Ukonom Creek	1098	549	59.559	107.347	A/D
Dillon Creek	1162	581	55.209	102.905	A/D
Salmon River	1357	679	58.333	81.788	A/D
Camp Creek	1466	733	52.865	71.474	A/D
Red Cap Creek	1511	756	49.403	67.773	A/D
Bluff Creek	1547	774	45.339	65.584	A/D
Trinity River	1609	805	41.415	59.672	A/D

Table 13. Geometry Information for the IG-Turwar reach (150-meter grid)

Location	Node	Element	x-coord	y-coord	Site Type
Pine Creek	1644	822	36.954	61.269	A/D
Tectah Creek	1850	925	24.557	79.833	A/D
Blue Creek	1908	954	22.306	86.220	A/D
1/4 mi bl Iron Gate	4	2	146.419	142.345	reporting
1/4 mi ab Cottonwood	84	42	138.117	137.743	reporting
1/4 mi ab Shasta	142	71	134.262	131.198	reporting
Walker Bridge	369	185	111.329	131.759	reporting
1/4 mi ab Scott	511	256	97.348	125.720	reporting
USGS Gage at Seiad Valley	672	336	80.887	133.289	reporting
1/4 mi ab Clear Cr.	998	499	62.908	118.058	reporting
1/2 mi ab Salmon (Ishi Pishi)	1352	676	58.231	82.372	reporting
USGS Gage at Orleans	1454	727	54.016	71.457	reporting
1/4 mi ab Bluff Cr.	1545	773	45.357	65.876	reporting
1/4 mi ab Trinity	1607	804	41.692	59.692	reporting
Martin's Ferry	1651	826	36.505	62.187	reporting
Young's Bar	1722	861	31.541	69.894	reporting
1/4 mi ab Blue Cr.	1906	953	22.177	85.992	reporting
USGS Gage nr Turwar	2024	1012	16.341	96.868	reporting

3.2.8.2 River Bed Elevation

Bottom elevations along the reach were estimated from USGS topographic maps and reported elevations at Iron Gate dam. These elevations determined bed slope. Reach elevations range from approximately sea level to roughly 2200 ft (671 m) MSL.

3.2.8.3 Cross-sections

Klamath River widths for the Iron Gate dam to Turwar reach were estimated from meso-habitat surveys compiled by US Fish and Wildlife Service (1997). This dataset included a reach-by-reach description of 1,741 units, or sections of the river, by habitat type, width, and maximum depth. Measurements were not uniformly spaced. Because measurement locations did not always coincide with the 1:24,000 x-y coordinates, field data were linearly interpolated to produce widths for model cross-sections. Large variations in river width were smoothed with a seven-point running average to provide estimates of bottom width for the model. From these estimated bottom widths, trapezoidal cross-sections were constructed at each node assuming 1:1 side slopes. Widths and other geometric characteristics for the Iron Gate to Turwar reach are summarized in Table 14.

Table 14. Klamath River, Iron Gate Dam to Turwar Reach Geometry Summary

Node spacing	150 meters
Number of nodes	2082 nodes in length
Length	190.54 miles from RM 0.00-190.54
Elevations	Range: 0-671 meters
Widths	Range: 17-340 meters
Side slopes	1:1
Data sources	UTM coordinates from CH2M HILL; Elevations estimated from USGS topographic maps
Notes	n/a

3.3 BOUNDARY CONDITIONS

Boundary conditions, often called "forcing functions," describe the changing state of flow, water quality, and meteorology along the boundaries of a modeling system. These conditions are applied at each time step and along each river and reservoir reach of the model. In the case of the Klamath River model used in this study, most boundary conditions are discrete field observations or values derived directly from discrete observations. To provide a downstream boundary condition, outflow is typically described for each river reach by a stage-flow relationship derived from the Manning's Equation and cross-sectional areas.

To take advantage of the relative strengths of the RMA and CE-QUAL-W2 models, the set of linked river and reservoir models in this study used RMA for river reaches and CE-QUAL-W2 for reservoir reaches. Time-steps through river reaches were constant at 1 hour (except for a 15-minute time-step used in solution of J.C. Boyle bypass and peaking reach hydrodynamics). CE-QUAL-W2 uses a variable time-step solution technique, so time-steps for reservoir reaches varied. Time-steps through reservoirs were typically sub-hourly (e.g., minutes), but simulation results were reported at 1-hour intervals to match the resolution of river reaches. The various reaches of the system are linked by passing flow and water quality downstream from one reach to the next. A reach-by-reach overview of inflows to, and outflows from, the entire Klamath River system is presented in this section. Detailed flow and water quality boundary conditions are presented by location and year in Appendix C.

3.3.1 Flow

Models of each reach, "sub-models" of the Klamath River model, are run separately in series. Beginning at the upstream end of the system, Link River, and progressing downstream to the Iron Gate to Turwar reach, the sub-models are typically run to simulate one year of boundary conditions at a time. A typical simulation begins with the simulation of one year of flow and water quality in the Link River reach. That year's simulated outflow and water quality from the Link River reach is passed as inflow to the Lake Ewauna to Keno reach, which is then run for the same year and produces inflow for the Keno River reach. Flows and water quality are passed so on downstream, until the entire river has been simulated for the year being studied.

3.3.1.1 Link River Reach

Link River carries water from Upper Klamath Lake to Lake Ewauna, 1.3 miles downstream. Some flow enters Link River as release from the dam, but a significant amount of flow is diverted through two powerhouse diversions and released into the river downstream of the dam. One diversion takes water along the west side of the river through a canal and short penstock to the Westside powerhouse and the other takes water along the east side of the river to the Eastside powerhouse. The Eastside powerhouse delivers water to the river above both USGS Gage 11507500 (Link River at Klamath Falls, OR) and the Westside powerhouse return that enters downstream of the USGS Gage. See Figure 2 for a schematic of the river.

Flow entering the reach at the upstream-most element (Link dam) is called Link Bypass flow and is reported by USBR. Eastside turbine flows were calculated as the difference between the Link River USGS Gage 11507500 and Link Bypass flow. Westside turbine flow is reported by PacifiCorp.

As with all river reaches, a stage-discharge relationship defines the downstream flow boundary condition for Link River. This relationship was derived from application of Manning's Equation and cross-sectional channel geometry at the end of the reach. Stage-discharge at the outflow of this reach is described by the power equation:

$$Q = 22.28 y^{2.29}$$
(3.1)

3.3.1.2 Lake Ewauna to Keno Dam Reach

Upstream inflow to the Lake Ewauna to Keno dam reach is assumed equal to Link River simulated outflow. Along the course of this reach, there are a number of tributary inflows and withdrawals. To match historic water surface elevations in the reservoir, a mass balance on measured flows and reservoir volume is used to calculate unquantified accretions and depletions. This accretion/depletion flow is distributed among the four irrigation diversion sites in the reach. Each inflow to, and withdrawal from, the reach is discussed below.

Stormwater Runoff

Stormwater runoff inflow to the reach was defined as a function of precipitation based on storm-water flows specified in an earlier simulation of this reach for calendar year 1992 conditions by ODEQ (1995). Stormwater inflow estimated for this simulation was compared to 1992 rainfall data recorded at the nearby KFLO meteorological station. Linear regression describes a strong relationship ($r^2 = 1.0$) between runoff and precipitation:

$$SWRO = 12.129 \times R$$
(3.2)

where:

    SWRO = total stormwater runoff, cms
    R   = precipitation, inches

In the earlier simulation by ODEQ (1995), total runoff was unevenly distributed among 11 locations in the reach and distribution varied with each rainfall event. Using estimates from this earlier study, the fraction of total annual runoff assigned to each site was calculated to produce an annual runoff factor. Total stormwater runoff was calculated daily using local precipitation data and Equation 3.2, and this total was then distributed among the same 11 sites using the annual runoff factors derived from the ODEQ (1995) simulation.

Columbia Plywood

An average monthly flow for Columbia Plywood discharge was estimated from maximum monthly flows reported to ODEQ. Average monthly flow for calendar year 2000-2004 was assumed constant at 0.01 cfs (0.0004 cms) throughout the year.

Klamath Falls Water Treatment Plant

Daily flows for the Klamath Falls Wastewater Treatment Plant (KFWWTP) were reported in monthly monitoring reports submitted to ODEQ. These flows are typically variable, ranging from 4 to 12 cfs, with less variability in the summer months. Flow records were available for 2000 and 2001. Flow data from 2000 were assumed for 2002-2004.

South Suburban Sanitation District

Daily flows from South Suburban Sanitation District were derived from flows reported five times a week in monthly monitoring reports submitted to ODEQ. Because plant discharges varied little from day to day and were relatively small, these data were averaged monthly and these average monthly flows were used as boundary flows to the model. Monthly average flows typically range from a little over 2 cfs to just over 4 cfs. Flow records were available for 2000 and 2001. Flow data from 2000 were assumed for 2002-2004.

Collins Forest Products #1 and #2

Daily inflow from Collins Forest Products discharge #1 and #2 was reported in monthly monitoring reports submitted to ODEQ. These flows, averaging about 1.4 cfs and 0.1 cfs for discharge #1 and #2, respectively, were input directly to the model. Flow records were available for 2000 and 2001. Flow data from 2000 were assumed for 2002-2004.

Lost River Diversion Channel

Daily inflows into Lake Ewauna from the Lost River Diversion Channel are gauged by USBR. USBR records describe both Lost River discharge to, and withdrawal from, Lake Ewauna to Keno Reach. For diversion from Lake Ewauna to Keno reach see the withdrawal section below.

Klamath Straits Drain

Inflow to Lake Ewauna from Klamath Straits Drain is gauged by USBR. Daily flows range from a minimum of 0.0 to a maximum of nearly 350 cfs, depending on season. High monthly variability occurs between February and September. Flows used in the simulations were taken directly from recorded information.

Klamath Reclamation Project Diversions

There are three withdrawals within Lake Ewauna for the Klamath Reclamation Project: Lost River, North Canal and ADY Canal. All three withdrawals are gauged daily by USBR. Lost River withdrawals range dramatically in summer months to a maximum of over 600 cfs. North Canal withdrawals are less variable and peak in summer and winter months at about 150 to 200 cfs. ADY Canal withdrawals follow the same pattern as those at North Canal but are of greater magnitude, reaching maxima of 400 to 500 cfs.

Non-Reclamation Irrigation Diversions

Due to a lack of available records describing non-USBR irrigation, daily withdrawal rates estimated in the previous simulation (ODEQ 1995) were applied for all simulation years. The irrigation season was assumed to extend from May 30 to September 30 (JD 152-274). Withdrawals peaked at a steady 60 cfs for Irrigator #7 and at a steady 14 cfs for Irrigators #2, #3, and #4. Outside the irrigation season, withdrawals were assumed to be zero for all four irrigators.

Accretion/Depletion

Net ungaged accretions and depletions from the system were determined using a water balance based on measured flows and the change in storage recorded at Keno dam (provided by PacifiCorp). This accretion/depletion was evenly distributed proportionally among the four irrigation withdrawal points.

Keno Dam Outflow

Hourly releases from Keno dam were taken from data recorded at USGS Gage 11509500 (Klamath River near Keno, Oregon). Outflow from the dam ranged from a maximum of over 4,000 cfs in spring to a minimum of under 500 cfs in summer.

3.3.1.3 Keno River Reach

The Keno River reach receives flow directly from Keno dam. No appreciable tributary contributions or diversions have been identified for this relatively short reach and accretions/depletions between Keno dam and J.C. Boyle dam were assigned to the J.C. Boyle reservoir reach.

A stage-discharge relationship defines the downstream flow boundary condition for Keno River reach. This relationship was derived from application of Manning's Equation and cross-sectional channel geometry at the end of the reach. Stage-discharge at the outflow of this reach is described by the power equation:

$$Q = 20.23y^{1.66} \tag{3.3}$$

3.3.1.4 J.C. Boyle Reservoir Reach

J.C. Boyle reservoir receives inflow directly from the Keno River reach. Because tributary flow records are limited, accretion/depletion flows for the reservoir were calculated and located at

Spencer Creek. Net reservoir accretion/depletion was calculated as the difference between daily average outflow and inflow, assuming constant water surface elevation.

Outflow from J.C. Boyle reservoir was calculated as the sum of recorded releases to the powerhouse canal, spill from the dam, bypass releases, and fish ladder releases. Hourly power canal flows and spill were taken from PacifiCorp records. Fish ladder and bypass releases were assumed constant at 80 cfs and 20 cfs, respectively.

3.3.1.5 J.C. Boyle Bypass and Peaking Reach

The J.C. Boyle bypass reach receives releases directly from J.C. Boyle dam (J.C. Boyle bypass flow), and ungaged inflow from a number of springs upstream of the powerhouse. The peaking reach receives inflow from the bypass reach and the J.C. Boyle powerhouse tailrace (peaking flow). Bypass and peaking flows are derived from measured J.C. Boyle dam releases as reported by PacifiCorp. The springs are represented by three separate inflows, each constant at 75 cfs (2.12 cms). Total spring inflow was 225 cfs (6.36 cms) for the duration of each simulation. Accretion/depletion for the J.C. Boyle bypass reach is accommodated in spring flow. Accretion/depletion for the peaking reach was calculated using a water balance between the USGS gage for the Klamath River below J.C. Boyle powerhouse and outflow from Copco dam, accounting for storage change in Copco reservoir. This accretion/depletion is evenly partitioned to the river and reservoir, with 50 percent applied to the J.C. Boyle peaking reach and 50 percent applied to Copco reservoir. Accretion/depletion for the peaking reach was placed at Stateline, to represent the ungaged inflows and diversions for agriculture that occur in the vicinity.

A stage-discharge relationship defines the downstream flow boundary condition for J.C. Boyle bypass and peaking reach. This relationship was derived from application of Manning's Equation and cross-sectional channel geometry at the end of the reach. Stage-discharge at the outflow of this reach is described by the power equation:

$$Q = 29.27y^{1.70} \tag{3.4}$$

3.3.1.6 Copco Reservoir Reach

Copco reservoir receives flow directly from the J.C. Boyle bypass and peaking reach. Hourly accretion/depletion for the reach was calculated from a water balance using gauged flows in the peaking reach upstream, Copco dam outflow, and daily change in reservoir storage (as described for the J.C. Boyle peaking reach above) and added to headwater inflow. As with J.C. Boyle reservoir, final accretion/depletion values were determined using the CE-QUAL-W2 water-balance utility "waterbalance.exe."

PacifiCorp reports hourly outflow from the dam to both the Copco powerhouse and spillway. Because intakes to the powerhouses have similar centerline elevations, the two powerhouse units were treated as a single outlet in simulations.

3.3.1.7 Iron Gate Reservoir Reach

Iron Gate reservoir receives flow directly from Copco dam. Sometimes during hydropower operations, release flows are immeasurably small. During these periods, a minimum flow of 0.035 cfs (0.001 cms) was assumed.

Accretion/depletion was calculated to complete a daily water balance as the difference between daily outflow and the sum of inflow and change in reservoir storage.

Records of tributary flow into Iron Gate reservoir (from Camp, Jenny, and Fall Creeks) are limited and insufficient for modeling. Therefore, accretion/depletion was placed at Jenny Creek, the source of greatest actual inflow, and flows for both Camp and Fall Creeks were set to very low values or zero. Camp Creek, represented as a branch of the model, was assigned a flow of 0.0035 cfs (0.0001 cms) for the entire year. Fall Creek inflow was set to zero. As with J.C. Boyle and Copco reservoirs, final accretion/depletion values were determined using the CE-QUAL-W2 water-balance utility "waterbalance.exe."

Powerhouse release and spill from Iron Gate reservoir was determined from PacifiCorp daily flow records. A constant additional flow of 50 cfs (1.42 cms) was assumed for lower fish hatchery releases. Upper fish hatchery releases were assumed zero.

3.3.1.8 Iron Gate to Turwar Reach

The Iron Gate dam to Turwar reach receives inflow directly from Iron Gate dam. Between Iron Gate dam and Turwar, the model accepts inflow from 23 tributary stream and rivers.

Five major tributaries to this reach are actively gauged, including the Shasta, Scott, Salmon, and Trinity Rivers, and Indian Creek. Inflows for minor tributaries were defined and quantified as daily accretion/depletions based on methods described by USGS (1995). Details of USGS methodology are included in Appendix D. The Scott and Trinity Rivers were assigned both USGS gauged flows and daily accretion/depletions. Model node and element numbers, and type of flow record employed for each tributary are summarized in Table 15.

Table 15. Element Flow Information for the IG-Turwar EC Simulation

Location	Node	Element	Flow Type
Bogus Creek	7	4	7 day average
Willow Creek	55	28	7 day average
Cottonwood Creek	86	43	7 day average
Shasta River	144	72	Daily measured
Humbug Creek	204	102	7 day average
Beaver Creek	319	160	7 day average
Horse Creek	468	234	7 day average
Scott River	513	257	Daily measured + A/D Ft. Jones to Klamath
Grider Creek	656	328	7 day average (A/D Scott to Seiad)
Thompson Creek	735	368	7 day average
Indian Creek	906	453	Daily measured
Elk Creek	925	463	7 day average

Table 15. Element Flow Information for the IG-Turwar EC Simulation

Location	Node	Element	Flow Type
Clear Creek	1000	500	7 day average
Ukonom Creek	1098	549	7 day average
Dillon Creek	1162	581	7 day average
Salmon River	1357	679	Daily measured
Camp Creek	1466	733	7 day average
Red Cap Creek	1511	756	7 day average
Bluff Creek	1547	774	7 day average
Trinity River	1609	805	Daily measured + A/D Hoopa to Klamath
Pine Creek	1644	822	7 day average
Tectah Creek	1850	925	7 day average
Blue Creek	1908	954	7 day average

Shasta River daily flows were taken from USGS Gage 11517500 (Shasta River near Yreka). Scott River daily flows were calculated from USGS Gage 11519500 (Scott River near Ft Jones) and accretion/depletions calculated per USGS (see Appendix D). Daily Indian Creek flows were taken from USGS Gage 11521500 (Indian Creek near Happy Camp). Salmon River daily flows were from USGS Gage 11522500 (Salmon River at Somes Bar). Trinity River daily flows were calculated from USGS Gage 11530000 (Trinity River at Hoopa) and accretion/depletions calculated per USGS (see Appendix D).

A stage-discharge relationship defines the downstream flow boundary condition for the Iron Gate to Turwar reach. This relationship was derived from application of Manning's Equation and cross-sectional channel geometry at the end of the reach. Stage-discharge at the outflow of this reach is described by the power equation:

$$Q = 266.83y^{1.67} \tag{3.5}$$

3.3.2 Water Quality

Water quality boundary conditions required for the Klamath River model include water temperature, dissolved oxygen, organic matter, nutrients, and algae. Others constituents may be simulated by one or the other of the numerical models that comprise the Klamath River model, but these other constituents are not common to the models used and are not discussed in detail here. Each model represents organic matter a little differently, so in passing organic matter from one model to the next a few simplifying assumptions are made. A description of the process used to pass simulation results from one model to the next is included in this section. The remainder of the section presents an overview of water quality boundary conditions for each inflow to the Klamath River model for the five years of simulations (2000–2004).

3.3.2.1 Model Linkage

As described for flow (in section 3.3.1), water quality is passed at each boundary between reaches. Both CE-QUAL-W2 and RMA11 model the same core set of water quality constituents, including water temperature, DO, BOD, NH3, NO3, PO4, and phytoplankton algae. These

constituents are passed directly from one model to the next. Values for other constituents are either assumed or derived.

Organic matter (OM) is an important water quality constituent that is represented by both models, but it is represented a little differently in each. For this application to the Klamath River, Watercourse Engineering modified the RMA-11 code so that OM is analogous to labile organic matter (LDOM and LPOM) in CE-QUAL-W2. The only difference is that both particulate and dissolved forms of labile organic matter are modeled as one in the new RMA-11. In the most current Watercourse version of RMA-11, there is no refractory organic matter (RDOM and RPOM in CE-QUAL-W2) and concentrations of these partitions are assumed to be zero. In transferring results from rivers to reservoirs, riverine OM is assumed to be partitioned 20 percent dissolved and 80 percent particulate, based on the ratio of dissolved and particulate OM that results from algae mortality as reported by Cole and Wells (2002)

The CE-QUAL-W2 reservoir models are set up to simulate residence time (AGE), iron (FE), coliform bacteria (COL1), and suspended solids (ISS1). These constituents are not explicitly simulated in the river reaches. Thus, headwater inflow values of these state variables are set to constants, as presented in Table 16, for all reservoirs. In this fashion AGE provides residence time for each reservoir. Iron, coliform, and suspended solids are not used in these analyses. RMA-11 simulated the entire nitrification process (conversion of ammonia to nitrite to nitrate), while CE-QUAL-W2 combines the two intermediate steps and represents the conversion from ammonia to nitrate. Thus, nitrite is not explicitly included in CE-QUAL-W2, but the oxygen demand of nitrification is effectively represented. Because nitrite levels are very low in the RMA-11 simulations, they are assumed negligible in all cases.

Table 16. Constant Water Quality Concentrations for Headwater Inflow to CE-QUAL-W2 Reservoirs

Variable	Description, units	Inflow value
TDS	Total dissolved solids (mg/L)	100
AGE	Residence time (days)	0
TIC	Total inorganic carbon (mg/L)	0
ALK	Alkalinity (mg/L)	25
FE	Iron (mg/L)	0
COL1	Coliform bacteria (MPN/100 mL)	15
ISS1	Suspended solids (mg/L)	60

3.3.2.2 Link River Reach

Water quality data for the Link River reach was derived from multiple sources. Grab samples collected by the Klamath Tribes at Fremont Bridge from 1994 to 2004 were used to describe seasonal water quality conditions at the upstream boundary of the reach. The Eastside and Westside turbines were assumed to have the same water source as the flows at Link dam (the upstream boundary) because of the short distance of this reach. Therefore, the same water quality was used for all three water sources in the Link River reach. Data sources for Link River water quality boundary conditions are outlined in Table 17.

Table 17. Data Sources for Boundary Conditions to the Link River Reach

Data	Source	Type
Temperature	U.S. Bureau of Reclamation	Hourly, seasonal estimates
Dissolved Oxygen	U.S. Bureau of Reclamation	Hourly, seasonal estimates
Water quality parameters[1]	Klamath Tribes	Seasonal estimates

[1] Water quality parameters include pH, conductivity, total phosphorus, orthophosphates, total nitrogen, nitrate + nitrite, ammonia, chlorophyll-a and phaeophytin.

Temperature: Records of water temperatures reported from USBR monitoring near Link dam (at A-Canal) during 2000-2004 were used to construct a composite of hourly inflow temperatures for the Link River.

Dissolved Oxygen: Very little field data are available for 2000 and 2001 to describe Link dam DO. Therefore, DO was assumed to be at saturation level, and saturation concentrations were calculated from the composite temperature record. After 2001, data from water quality probes deployed by USBR were used to describe the DO boundary condition.

BOD and Organic Matter (OM): BOD concentrations were estimated for 2000 and 2001 from data collected during a 2002 sampling program completed by USBR. For 2000 and 2001, a baseline BOD concentration of 2 mg/l as background was used from November through April. This level of BOD was ramped up to 10 mg/l for the summer period (June through August). The remaining BOD was assigned to the OM compartment of the model. Available data from 2002-2004 were used to create a boundary condition for BOD and OM; however, in this case, BOD was converted to OM and BOD was not applied. The general outcome among the simulations is similar because BOD and OM are treated similarly.

Nutrients and Algae: Water quality boundary conditions for the Link River were calculated from Upper Klamath Lake grab samples collected by the Klamath Tribes from 1994-2004 at the Fremont Bridge (Kann, 2001). Fremont Bridge was selected because of its proximity to Link dam.

Between 1994 and 2004 over 70 grab samples were taken at multiple depths and analyzed for nutrient concentrations. Because there were insufficient samples in 2000 to identify a boundary condition for the Link River reach, a composite of all data was used to create monthly average concentrations that represented general seasonal conditions. Comparison of field data suggested that conditions in the Fremont Bridge area were generally well mixed (i.e., minimal vertical variation for the selected water quality constituents). Therefore, samples from all depths were used in the determination of monthly average concentrations. For 2001-2004 estimated of nutrient concentrations at Link dam were made based on USBR, PacifiCorp, and Klamath Tribes data.

3.3.2.3 Lake Ewauna to Keno Reach

Inflow locations, data sources, and data and model resolution are summarized in Table 18, followed by descriptions of each data set.

Table 18. Temperature Data for Inflow Locations, Including Data Source, and Data and Model Resolution

Location	Source	Data Resolution	Model Input Resolution
Link River	USBR	Hourly, other	Hourly, other [a]
Distributed tributary	Estimated	n/a	Annual
Stormwater	Estimated	n/a	Annual
Columbia Plywood	ODEQ	Monthly	Monthly
KFWTP	ODEQ/estimated	Daily	Daily
South Suburban Sanitation District	ODEQ	Daily	Monthly
Collins Forest Products #1, 2	ODEQ	Daily	Daily
Lost River	USBR	Semi-monthly	Semi-monthly
Klamath Straits Drain	USBR	Hourly	Daily, other [a]

[a] Hourly data was not available for all periods.

Headwater inflow: Water quality of headwater inflow to the Lake Ewauna to Keno reach is taken directly from output from the Link River reach.

Accretion/Depletion: Accretions and depletions to the Lake Ewauna reach were assumed to represent groundwater exchange within the reach. A constant inflow temperature of 12.0°C was assumed for all simulation years.

Other accretion/depletion constituent concentrations were taken from the 1992 Wells simulation (ODEQ, 1995). Wells' simulation covered only part of the calendar year, from JD 152 to JD 274. Prior to JD 152, concentrations were assumed to be equal to concentrations on JD 152. After JD 274, concentrations were assumed to be equal to those on JD 274.

Stormwater runoff: Stormwater runoff water quality from the previous ODEQ (1995) simulation was used in the simulations for this study. These concentrations were constant for each constituent throughout entire year.

Columbia Plywood: Monthly temperatures reported by Columbia Plywood to ODEQ were used as model input. These temperatures range from 13.3°C in winter to 21.1°C in summer.

Monitoring reports generally provide average monthly pH, biological oxygen demand (BOD) and total suspended solids (TSS). Results for a single sample were reported for 2000 (December) and eight samples were taken in 2001. An average of the nine concentrations reported from December 2000 through December 2001 was used to represent a constant annual input value of 8 mg/L of BOD and 16 mg/L TSS. Values for other water quality parameters were taken from the previous simulation (ODEQ, 1995). ODEQ data from 2000 and 2001 were assumed, with 2000 being applied for 2002-2004.

Klamath Falls Wastewater Treatment Plant (KFWTP): The treatment plant began reporting effluent water temperature in July 2001. To estimate effluent temperatures prior to this date, a

simple linear regression ($r^2 = 0.89$) was used to describe daily effluent (°C) as a function of daily influent water temperature (°C):

$$T_{effluent} = 0.8952(T_{influent}) + 2.653 \tag{3.6}$$

The regression was based on data from July 2001 through February 2002. Resulting temperatures for 2000 range from a low of about 15°C to a high of about 23°C with a brief spike in late summer of over 25°C.

Constituent concentrations for KFWTP were based on monthly ODEQ reports and the previous ODEQ (1995) simulation. Both dissolved oxygen and suspended solids were reported and showed little day-to-day variation, so monthly average values were calculated for model input. Monthly BOD concentrations were estimated from samples collected at biweekly intervals based on ODEQ reports. All other data are monthly estimates based on the previous ODEQ (1995) simulation. ODEQ data from 2000 and 2001 were assumed, with 2000 being applied for 2002-2004.

South Suburban Sanitation District: Average monthly water temperatures for South Suburban Sanitation District effluent were calculated from data gathered five times a week and reported in monthly monitoring reports submitted to ODEQ. These temperatures range from 2.5°C in winter to below 21°C in summer.

South Suburban Sanitation District also reports DO, BOD, total suspended solids (TSS), total phosphorus, ammonia, nitrate, and pH to ODEQ. The frequency of reporting varied for each parameter, with DO and pH reported five times a week, BOD and TSS reported twice a week, and all nutrients reported once a month. For use in this model, all data were converted to monthly averages. Orthophosphate was estimated as 50 percent of total phosphorous concentrations because no data were available. Temperature and pH were used to estimate monthly average values for alkalinity and total inorganic carbon (Snoeyink and Jenkins, 1980). Total dissolved solids (TDS) were estimated to be 200 mg/L, the same as in the previous ODEQ (1995) simulation. Several parameters were set to zero because there was no available information about their likely concentrations. These parameters included iron, refractory and labile particulate organic matter, and algae concentration. ODEQ data from 2000 and 2001 were assumed, with 2000 being applied for 2002-2004.

Collins Forest Products #1 and #2: Daily measured temperatures for the #1 and #2 discharges from Collins Forest Products were reported in the monthly monitoring reports submitted to ODEQ and were used directly in model input. These temperatures, similar for both discharges, range from about 3°C in winter to over 25°C in summer.

BOD and TSS concentrations, reported twice a week in the ODEQ reports, were combined to produce monthly average values. Other constituent concentrations were estimated from input data for these discharges, called Weyerhaeuser #1 and #3, in the previous ODEQ (1995) simulation. Collins Forest Products is the current owner of the same facilities that Weyerhaeuser owned in 1992. ODEQ data from 2000 and 2001 were assumed, with 2000 being applied for 2002-2004.

<u>Lost River Diversion:</u> Temperatures for the Lost River Diversion input were estimated from bimonthly measurements taken in the Lost River at Wilson Reservoir by USBR between December 28, 1999, and December 18, 2000. These temperatures range from a low of 2.2°C in winter to a high of 30°C in summer.

Other constituent concentrations were estimated from either the USBR measurements, Klamath Straits data from 2000 (DO), Link dam 2002 grab samples, or from the previous ODEQ (1995) simulation. Wilson Reservoir data were used only during periods when the Lost River diversion channel was flowing into the Klamath River.

<u>Klamath Straits Drain (KSD):</u> The temperature record for Klamath Straits Drain is a composite of hourly measurements by USBR at both KSD near Highway 97 and KSD at Stateline, averaged to daily temperatures. Daily average air temperature, as reported at the KFLO meteorological station, was used as a surrogate for water temperature when no data were available from either site. Sources of data for year 2000 are listed in Table 19.

Table 19. Sources of Temperature Data for KSD in Year 2000

Period:	1/1-1/14/00	1/15-3/16/00	3/20-4/6/00	4/6-5/2/00	5/2-11/22/00	11/23-12/31/00
Source:	KFLO air	Mouth of KSD	KSD at Stateline	Mouth of KSD	Mouth of KSD	KFLO air

If daily average air temperature was less than 0.0ºC, a water temperature of 0.0ºC was used. The composite temperature record for KSD ranges from 0.0ºC in winter to over 25.0ºC in summer.

DO and TDS concentrations were taken from data collected by a USBR datasondes deployed from January through November 2000 in Klamath Straits Drain. Data gaps were filled with linear interpolation. Monthly estimates for ammonia, nitrate, orthophosphate, algae, and alkalinity concentrations were based on USBR grab samples collected in 2000. All other constituent concentrations were estimated from the previous ODEQ (1995) simulation.

3.3.2.4 Keno River Reach

<u>Headwater inflow:</u> Upstream boundary conditions for the Keno River reach are defined by simulated hourly water quality from the Lake Ewauna to Keno reach. There is no other inflow to this reach.

3.3.2.5 J.C. Boyle Water Quality Data

<u>Headwater inflow:</u> Inflow water quality to J.C. Boyle reservoir is taken from simulated hourly water quality from the Keno River reach.

<u>Accretion/Depletion (Spencer Creek):</u> Accretion/depletions, representing Spencer Creek inflow to this reach, were added to Klamath River inflow at the headwaters of the reservoir and were assumed to have ambient river water quality.

3.3.2.6 J.C. Boyle Bypass-Peaking Reach Water Quality Data

Headwater inflow: The quality of water released to the J.C. Boyle bypass reach and through the J.C. Boyle powerhouse was assumed equal to simulated quality of outflow from J.C. Boyle Dam. Transit time between J.C. Boyle dam and the powerhouse tailrace, a distance of roughly 3 miles, is only about 20 minutes at peaking flows (T. Olson, PacifiCorp, personal communication). Because transit time is so small, water quality concentrations at the tailrace are assumed to immediately reflect concentrations at the dam (i.e. there is no time lag between concentrations at the tailrace and at the dam).

Springs: Water quality of the springs that flow into the J.C. Boyle bypass reach was assumed to be constant throughout the year. Water temperatures of the springs was assumed to be 11.0°C, DO was assumed to be 9.7 mg/L (saturation at 3600 ft elevation), and both nitrate and orthophosphate were assumed to be 0.15 mg/L based on field observations at the top and bottom of the bypass reach. All other constituent concentrations were assumed to be zero.

Accretion/depletions (Stateline): Accretions applied at Stateline were assumed to enter at the ambient water quality of the river. No water quality was assigned to accretions/depletions in this reach.

3.3.2.7 Copco Reservoir

Headwater inflow: Inflow water quality to Copco reservoir is taken from simulated hourly water quality from the J.C. Boyle bypass-peaking reach.

Accretion/depletions: Accretion/depletions for this reach were added to Klamath River inflow at the headwaters of the reservoir and were assumed to have ambient river water quality.

3.3.2.8 Iron Gate Reservoir

Headwater inflow: Inflow water quality to Iron Gate reservoir is assumed equal to simulated quality of outflow from Copco reservoir. During off-peak hours, when simulated outflow from Copco dam is zero, a small nominal inflow is specified and this inflow is assigned water quality from the last time step for which there was a release from Copco dam.

Accretion/depletion and tributary inflow: Because no water quality data are available for these inflows, all tributary water quality (including accretion/depletions applied at Jenny Creek) is assigned the estimated monthly water quality of Shovel Creek, on the Iron Gate to Turwar reach. Shovel Creek, like Jenny Creek, flows out of the Cascades mountain range and is assumed to be representative of water quality conditions in tributaries to Iron Gate reservoir.

3.3.2.9 Iron Gate to Turwar Reach

Headwater inflow: Inflow water quality to the Iron Gate to Turwar reach is assumed equal to the simulated quality of outflow from Iron Gate reservoir.

Tributaries: Major tributaries to this reach include the Shasta, Scott, Salmon, and Trinity rivers. Typically, water temperature has been reported continuously (i.e., every hour) for these major

tributaries. Although these records are largely intact, data gaps did exist. Generally Scott and Shasta River temperatures were used to fill respective data gaps among the two streams; similarly for the Salmon and Trinity River.

For all simulation years, water temperatures of minor tributaries to this reach, except Blue Creek, were based on data collected by U.S. Forest Service (USFS) between 1994 and 2001 (Appendix E). The Yurok Tribe provided Blue Creek water temperatures data. The USFS temperature database contains all of the stream temperature records available in the Klamath National Forest stream temperature database, as of October 17, 2002. This includes a total of almost 650,000 individual stream records. Generally, USFS monitoring efforts did not provide long-term datasets at any one location, but rather several locations were monitored for intermittent periods. To provide representative temperature for the various minor tributaries, composite hourly temperature traces were constructed for each creek. These composite datasets were used to calculate monthly average temperatures for each tributary. Monthly temperatures are presented in Table 20.

Table 20. Minor Tributary Inflow Temperatures for Iron Gate to Turwar Reach Model

JDAY	Temperature, ºC														
	1	15	46	75	106	136	167	197	228	259	289	320	350	366	367
Bogus Creek	0.13	0.19	0.52	3.39	7.79	12.43	12.76	14.06	14.50	12.43	8.31	2.87	0.06	0.13	0.13
Beaver Creek	4.00	4.25	4.85	6.98	7.79	8.68	11.16	14.03	15.55	14.31	11.09	4.79	4.04	4.00	4.00
Horse Creek	4.00	4.25	4.85	6.98	7.79	8.68	11.09	13.13	14.08	13.64	11.09	4.79	4.04	4.00	4.00
Grider Creek	4.00	4.25	4.85	6.98	7.79	8.68	11.09	16.31	16.82	13.95	10.80	4.79	4.04	4.00	4.00
Thompson Creek	7.89	7.76	8.25	8.23	10.00	10.96	14.10	15.37	16.79	15.79	13.35	9.91	8.01	7.89	7.89
Indian Creek	5.00	5.11	5.55	6.76	7.33	8.74	11.61	16.88	18.41	15.69	12.08	5.74	4.60	5.00	5.00
Elk Creek	4.00	4.25	4.85	6.98	7.79	8.68	11.09	17.62	18.15	14.95	11.09	4.79	4.04	4.00	4.00
Clear Creek	5.00	5.13	5.50	6.95	7.39	8.76	11.96	15.78	17.29	15.06	11.83	5.45	4.56	5.00	5.00
Ukonom Creek	5.00	5.05	5.26	6.74	7.38	8.17	10.71	13.05	13.95	12.37	10.66	5.52	4.88	5.00	5.00
Dillon Creek	5.00	6.93	6.19	7.67	9.52	12.46	15.49	20.21	18.58	16.92	11.80	7.63	4.93	5.00	5.00
Camp Creek	7.89	7.76	8.25	8.23	10.00	10.96	14.10	15.37	16.79	15.79	13.35	9.91	8.01	7.89	7.89
Red Cap Creek	6.50	6.93	6.19	7.67	9.52	12.46	15.49	20.30	19.37	16.62	13.06	9.22	6.23	6.50	6.50
Bluff Creek	7.89	7.76	8.25	8.23	10.00	10.96	14.10	15.37	16.79	15.79	13.35	9.91	8.01	7.89	7.89
Pine Creek	7.89	7.76	8.25	8.23	10.00	10.96	14.10	15.37	16.79	15.79	13.35	9.91	8.01	7.89	7.89
Tectah Creek	7.90	7.76	8.26	8.18	9.94	10.02	12.51	13.73	14.10	14.48	13.50	9.98	8.03	7.90	7.90
Blue Creek	7.89	7.76	8.25	8.23	10.00	10.96	14.10	15.37	16.79	15.79	13.35	9.91	8.01	7.89	7.89

Other constituent concentrations, in either major or minor tributaries, are not nearly as well documented as water temperature. To create a record of DO concentrations, saturation conditions were assumed everywhere. DO in all tributaries was estimated assuming 100 percent saturated conditions based on observations that most of these rivers and streams reach the Klamath River after flowing through:

- Steep canyon reaches that are several miles long

- Watersheds that have little or no water resources development
- Watersheds where organic loads and other oxygen-demanding processes are modest

Review of available data (USBR, 2003) indicates that this is a reasonable assumption for modeling applications. Diurnal variations due to primary production are assumed to be small and are not represented in these estimates.

Oxygen saturation concentrations were calculated from water temperature and atmospheric pressure, corrected for elevation. Because atmospheric correction along the reach was small, average elevations for three sub-reaches were used in the calculation. Average elevation from Iron Gate dam to the USGS Gage at Seiad Valley (1759.9 ft (536.4 m)) was used to correct atmospheric pressure for all tributaries within that section of the reach. Likewise, the average elevation for USGS Gage at Seiad Valley to Trinity River reach (810.0 ft (246.9 m)) and from the Trinity River to the end of the IG-Turwar reach (150.0 ft (45.7 m)) were used to correct atmospheric pressure for all tributaries within those sections of the reach. Methodologies for dissolved oxygen saturation calculation and atmospheric pressure correction are included in Appendix F.

Concentrations for all other constituents (e.g., nutrients, BOD, and algae) are estimated seasonally from grab samples taken by EPA (1997), USFWS (1999), and USBR (2003). Overall, there were little data available for most tributaries, and minor tributaries generally had no water quality data of this type available. The Shasta and Scott Rivers had sufficient data from USBR (2003) to represent seasonal variations only. Many of these tributary watersheds are lightly populated, have minimal water resource development and, although active timber management areas reside within several tributary watersheds, water quality out of most tributaries is of good quality. Estimated water quality boundary conditions for all tributaries of the Iron Gate to Turwar reach are summarized in Table 21.

Table 21. Water Quality Boundary Conditions for Constituent Concentrations for Klamath River Tributaries Between Iron Gate Dam and Turwar

Parameter		Shasta R.		Scott R [a]		All Other Tributaries [b]
		1/1-7/15	7/16-12/31	1/1-7/15	7/16-12/31	1/1-12/31
Organic N (D [c])	(mg/L)	0.45	0.45	0.20	0.20	0.15
NH_4^+	(mg/L)	0.15	0.05	0.15	0.05	0.05
NO_2^-	(mg/L)	0.00	0.00	0.00	0.00	0.00
NO_3^-	(mg/L)	0.05	0.05	0.15	0.05	0.05
Organic P (D [c])	(mg/L)	0.05	0.05	0.05	0.05	0.05
PO_4^{3-}	(mg/L)	0.45	0.15	0.10	0.05	0.05
BOD	(mg/L)	2.00	2.00	2.00	2.00	2.00
Algae	(mg/L)	1.00	1.00	1.00	1.00	1.00
Dissolved Oxygen	(mg/L)	Based on saturation dissolved oxygen				

[a] based on synoptic at mouth

[b] Including Salmon River, Trinity River and all minor tributaries

ᶜ D – Dissolved

3.3.3 Meteorology

Meteorological input data, used to calculate heat flux and light intensity in the model, include air temperature (°C), wet bulb temperature (°C), wind speed (m/s), cloud cover (scale 0.0-1.0) and atmospheric pressure (mb). Typically, cloud cover, atmospheric pressure, and wet bulb temperature are derived from observed data.

To best represent meteorological conditions, the 260-mile length of the Klamath River is divided into three climate zones. Zone 1 extends from Upper Klamath Lake (RM 255; 4,135 ft (1,259 m) above MSL) to J.C. Boyle dam (RM 226; 3759.8 ft (1146 m) above MSL) and represents the climate of higher elevations. Zone 2 is a mid-zone extending from J.C. Boyle dam to Seiad (RM 129; 1,318.9 ft (402 m) above MSL). Zone 3 represents the more coastal climate of lower elevations, extending from Seiad to Turwar (RM 5.0; approximately sea level).

Meteorological data for Zone 1 were derived from observations near Klamath Falls, OR. This meteorological station, KFLO (4,100 ft (1,249.7 m) above MSL), is operated by the Pacific Northwest Cooperative Agricultural Weather Network, and provided dry bulb temperature, dew point temperature, relative humidity, cumulative solar radiation, and wind speed. Atmospheric pressure was calculated based on an assumed elevation of 4100 ft (1250 m) and was assumed constant at the calculated value of 870 mb throughout the simulation period.

Meteorological data for Zone 2 were derived from observations at Brazie Ranch (3,020 ft (920 m) above MSL), near Yreka, CA. This meteorological station is operated by the California Department of Forestry, and provided dry bulb temperature, relative humidity, cumulative solar radiation, and wind speed. Atmospheric pressure was calculated based on an assumed elevation of 3020 ft (920 m) and was assumed constant at the calculated value of 910 mb throughout the simulation period.

Meteorological data for Zone 3 were derived from observations at the Trinity River near Hoopa, CA (375 ft (114 m) above MSL). This meteorological station is operated jointly by USGS and the California Department of Water Resources, and provided dry bulb temperature, relative humidity, cumulative solar radiation, and wind speed. Atmospheric pressure was calculated based on elevation and assumed constant at 992 mb throughout the simulation period.

Cloud cover and wet bulb temperatures for all zones are derived from reported data. Cloud cover is calculated from the daily summation of solar radiation, using an ideal sine wave representation of the maximum possible solar radiation throughout the year to determine the ratio of measured radiation to total radiation. Wet bulb temperature is calculated from relative humidity, atmospheric pressure, and air temperature.

3.4 MODEL PARAMETERS

In addition to system geometry and boundary conditions, the numerical models that simulate flow and water quality of the Klamath River depend upon parameters, including coefficients and constants, to describe the many relationships that govern the simulations. These relationships

describe the effects of system geometry and boundary conditions on state variables (e.g. the effect of surface area and solar radiation on water temperature) and interactions between state variables (e.g. the effect of organic matter decay on DO). Details of all the relationships simulated by the RMA and CE-QUAL-W2 models are presented in model documentation (King, 2002; Cole, 2002).

Typically, model parameters may be grouped as either "reach-dependent" or "global." Global parameters apply to the entire system. Either these parameters are not expected to change throughout the system or there is not enough information available to indicate how they would change throughout the system. Reach-dependent parameters change from reach to reach within the system. These parameters generally reflect special characteristics of particular sections of the system. Depending on the scope of application, values for both global and reach-dependent parameters may be derived from calibration. The Klamath River has been modeled as one system and parameter values have been chosen for consistency throughout the system. But, because the numerical models used in this study are formulated differently, parameter values are not always comparable between the two. Reach-dependent parameters for river and reservoir reaches are presented in Table 22 and Table 23, respectively. Global parameters for river and reservoir reaches are presented in Table 24 and Table 25, respectively.

Most biological and chemical rate reactions are dependent upon temperature. Higher temperatures typically result in faster reaction rates. Reaction rates can respond dramatically to changes in temperature, so temperature correction of rates is an important feature of the numerical models used in these simulations. The RMA models use a van't Hoff-Arrhenius equation (Tchobanoglous and Schroeder, 1985) to correct for temperature changes. Depending on the reaction, CE-QUAL-W2 uses either van't Hoff-Arrhenius or a user-defined correction curve. For reference, temperature-based correction factors used in RMA11 are listed in Table 26.

Table 22. RMA-2 and RMA-11 Reach-Dependent Parameters (River Reaches)

Variable	Model	Description, units	Link River	Keno River	J.C. Boyle Bypass-Peaking	Iron Gate-Turwar
	RMA2	Hydrodynamic time step, hr	1	1	0.25	1
	RMA11	Water quality time step, hr	1	1	1	1
	RMA2, RMA11	Spatial resolution, m	75	75	75	150
	RMA2	Slope factor	0.8	0.9	0.95	0.8/0.5*
EXTINC	RMA11	Light Extinction coefficient, 1/m	1.5	1.5	1.5	0.3
ELEV	RMA11	Elevation of site, m	1255	1192	975	287

 * From IG Dam to Orleans SF=0.8; from Orleans to Turwar SF=0.5

Table 23. CE-QUAL-W2 Reach-Dependent Parameters (Reservoirs)

Parameter	Description	LE-Keno	JC Boyle	Copco	Iron Gate
LAT	Latitude, degrees	42.13	42.12	42.12	42.97
LONG	Longitude, degrees	121.95	122.05	122.33	122.42
EBOT	Bottom elevation of waterbody, m	1237.30	1143.75	761.09	663.78
TSED	Sediment (ground) Temperature, C	8.5	12	12	12
AR	Maximum algal respiration rate, 1/day	0.10	0.05	0.05	0.05
SOD	Zero-order sediment oxygen demand, g O2/m2day	3	1	1	1

Table 24. RMA-2 and RMA-11 Global Parameters

Variable	Description, units	Value
	Manning roughness coefficient	0.04
	Turbulence factor, Pascal-sec	100
	Longitudinal diffusion scale factor	0.10
LAT	Latitude of site, degrees	41.5
LONG	Longitude of site, degrees	122.45
EVAPA	Evaporative heat flux coeff a, m/mbar-hr	0.000015
EVAPB	Evaporative heat flux coeff b, sec/mbar-hr	0.000010
ALP0	Chl a to algal biomass conversion factor, phytoplankton, mg Chl_a to mg-A	67
ALP1	Fraction of algal biomass that is nitrogen, phytoplankton, mg-N/mg A	0.07
ALP2	Fraction of algal biomass that is phosphorous, phytoplankton, mg-P/mg A	0.01
MUMAX	Maximum specific growth rate, phytoplankton, 1/d	0.10
RESP	Local respiration algae, phytoplankton, 1/d	0.10
RESP	Local mortality rate of algae, phytoplankton, 1/d	1.0
SIG1	Settling rate of algae, phytoplankton, 1/d	0
KLIGHT	Half saturation coefficient for light, phytoplankton, KJ m-2 s-1	0.01
PREFN	Preference factor for NH3-N, phytoplankton	0.60
ABLP0	Chl a to algal biomass conversion factor, bed algae, mg Chl_a to mg-A	50
BMUMAX	Maximum specific growth rate, bed algae, 1/d	1.15
BRESP	Local respiration rate of algae, bed algae, 1/d	0.20
GRAZE	Local respiration rate of algae, bed algae, 1/d	0.10
BMORT	Local respiration rate of algae, bed algae, 1/d	0.20
KBLIGHT	Half-saturation coefficient for light, bed algae, KJ m-2 s-1	0.01
PBREFN	Preference factor for NH3-N, bed algae	0.75
BET1	Rate constant: biological oxidation NH3-N, 1/d	0.30
BET2	Rate constant: biological oxidation NO2-N, 1/d	0.50
BET3	Rate constant: hydrolysis organic matter to NH3-N, 1/d	0.20
KNINH	First order nitrification inhibition coefficient, mg-1	0.60
K1	Deoxygenation rate constant: BOD, 1/d	0.20
-	Minimum reaeration rate constant (Churchill formula applied), 1/d	4.0
KNITR	Michaelis-Menton half saturation constant: nitrogen, phytoplankton, mg/l	0.014
KPHOS	Michaelis-Menton half saturation constant: phosphorous, phytoplankton, mg/l	0.003
ABLP1	Fraction of algal biomass that is nitrogen, bed algae, mg/l	0.07
ABLP2	Fraction of algal biomass that is phosphorus, bed algae, mg/l	0.01
KBNITR	Half-saturation coefficient for nitrogen, bed algae, mg/l	0.014

Table 24. RMA-2 and RMA-11 Global Parameters

Variable	Description, units	Value
KBPHOS	Half-saturation coefficient for phosphorus, bed algae, mg/l	0.003
ALP3	Rate O2 production per unit of algal photosynthesis, phytoplankton, mg-O/mg-A	1.5
ALP4	Rate O2 uptake per unit of algae respired, phytoplankton, mg-O/mg-A	1.5
ABLP3	Rate O2 production per unit of algal photosynthesis, bed algae, mg-O/mg-A	1.5
ABLP4	Rate O2 uptake per unit of algae respired, bed algae, mg-O/mg-A	1.5
ALP5	Rate O2 uptake per unit NH3-N oxidation, mg-O/mg-N	3.43
ALP6	Rate O2 uptake per unit NO2-N oxidation, mg-O/mg-N	1.14
SIG6	BOD settling rate constant, 1/d	0.0

Table 25. CE-QUAL-W2 Global Parameters

Parameter	Description	Value
DLT MIN	Minimum time step, sec	5
DLT MAX	Maximum time step, sec	500
SLOPE	Waterbody bottom slope	0
CFW	C coefficient in the wind speed formulation	1
WINDH	Wind speed measurement height, m	2
FI	Interfacial friction factor	0.04
TSEDF	Heat loss added back to water from bed, fraction	0.1
EXH2O	Extinction for pure water, m-1	1.00
ASAT	Light intensity at a max photosynthesis, W/m2	100
AFW	A coefficient in the wind speed formulation	9.2
CBHE	Coefficient of bottom heat exchange, W/m2sec	0.3
AG	Maximum algal mortality rate, 1/day	2
AR	Maximum algal respiration rate, 1/day	0.05
AE	Maximum algal excretion rate, 1/day	0.04
AM	Maximum algal growth rate, 1/day	0.1
EG	Maximum epiphyton mortality rate, 1/day	2
ER	Maximum epiphyton respiration rate, 1/day	0.04
EE	Maximum epiphyton excretion rate, 1/day	0.04
EM	Maximum epiphyton growth rate, 1/day	0.1
O2NH4	Rate O2 uptake per unit Ammonia-N oxidation, mg-O/mg-N	4.57
SEDK	Sediment decay rate, 1/day	0.04
AS	Algal settling rate, m/day	1.0

Table 25. CE-QUAL-W2 Global Parameters

Parameter	Description	Value
ALGP	Stoichiometric equivalent between algal biomass and phosphorus	0.1
ALGN	Stoichiometric equivalent between algal biomass and nitrogen	0.07
ALGC	Stoichiometric equivalent between algal biomass and carbon	0.45
EP	Stoichiometric equivalent between epiphyton biomass and phosphorus	0.01
EN	Stoichiometric equivalent between epiphyton biomass and nitrogen	0.07
EC	Stoichiometric equivalent between epiphyton biomass and carbon	0.45
LDOMDK	Labile DOM decay rate, 1/day	0.2
RDOMDK	Refractory DOM decay rate, 1/day	0.001
LRDDK	Labile to refractory DOM decay rate, 1/day	0.01
LPOMDK	Labile POM decay rate, 1/day	0.2
RPOMDK	Refractory POM decay rate, 1/day	0.001
LRPDK	Labile to refractory POM decay rate, 1/day	0.01
POMS	POM settling rate, m/day	0.5
ORGP	Stoichiometric equivalent between organic matter and phosphorus	0.01
ORGN	Stoichiometric equivalent between organic matter and nitrogen	0.07
ORGC	Stoichiometric equivalent between organic matter and carbon	0.45
PO4R	Sediment release rate of phosphorus, fraction of SOD	0.03
NH4R	Sediment release rate of ammonium, fraction of SOD	0.07
NH4DK	Ammonium decay rate, 1/day	0.1
NO3DK	Nitrate decay rate, 1/day	0.1
NO3S	De-nitrification rate from sediments, m/day	0
CO2R	Sediment carbon dioxide release rate, fraction of SOD	0.01
O2AR	Oxygen stoichiometry for algal respiration	1.5
O2AG	Oxygen stoichiometry for algal primary production	1.5
AHSN	Half-saturation constant: nitrogen, phytoplankton, mg/l	0.014
AHSP	Half-saturation constant: phosphorous, phytoplankton, mg/l	0.003
EHSN	Half-saturation coefficient for nitrogen, epiphyton, mg/l	0.014
EHSP	Half-saturation coefficient for phosphorus, epiphyton, mg/l	0.003

Table 26. RMA-11 Temperature-Based Rate Correction Factors

Variable	Description, units	Water	Bed
THET1	Algal growth rate temperature factor	1.047	1.047
THET2	Algal respiration rate temperature factor	1.047	1.047
THET3	Algal settling rate temperature factor	1.047	1.000
THET4	Organic nitrogen decay rate temperature factor	1.047	1.000
THET5	Organic nitrogen settling rate temperature factor	1.024	1.000
THET6	Ammonia nitrogen decay rate temperature factor	1.083	1.000
THET7	Ammonia nitrogen benthic sources rate temperature factor	1.074	1.000
THET8	Nitrite nitrogen decay rate temperature factor	1.047	1.000
THET9	Organic phosphorous decay rate temperature factor	1.047	1.000
THET10	Organic phosphorous settling rate temperature factor	1.024	n/a
THET11	Orthophosphate benthic sources rate temperature factor	1.074	n/a
THET12	BOD decay rate temperature factor	1.015	n/a
THET13	BOD settling rate temperature factor	1.024	n/a
THET14	DO benthic demand rate temperature factor	1.000	n/a
THET15	DO reaeration rate temperature factor	1.024	n/a

3.5 CALIBRATION AND VALIDATION

Model calibration and validation are the processes of adjusting parameters to fit model results to field observations (calibration) and testing the model with an independent set of boundary conditions and field observations (often termed validation). These processes provide a means to test the model and quantify its ability to replicate field conditions under different hydrological, meteorological, and water quality conditions. In this section, results of model calibration and validation are presented for each of twenty locations along the river. River reaches were calibrated for flow, and details of that calibration process are given in the Flow Calibration section. Reservoir reaches were not calibrated for flow, but rather stage. Inflows and outflows are specified as input values in CE-QUAL-W2 and these were determined based on changes in observed or assumed storage. Because inflow, outflow, and water surface level are all used to drive the reservoir models, there are no independent data by which to calibrate the hydrology of the reservoirs. Existing data are insufficient to test actual hydrodynamic performance of these models, but simulated reservoir elevation is used as a proxy.

All river and reservoir reaches were calibrated for water temperature and dissolved oxygen. To attain dissolved oxygen calibration, parameters that affect nutrients, phytoplankton, or benthic algae were typically examined. Where data were available for in sufficient quantity and quality, nutrient and algae observations were compared with simulated values to assess model performance. Comparisons of simulated and observed temperature, dissolved oxygen, nutrients, and algae for each of the five simulation years (2000-2004) are presented in this section.

Although reservoir models were applied over a calendar year during calibration, there were generally little or no data to calibrate during winter months until later years and then, generally, only for temperature. Nonetheless, model results are presented for the entire year. Results of calibration-validation show that the Klamath River model represents the majority of system processes and translates water quality conditions downstream through the system with significant accuracy. Certain components, such as flow and temperature, are well represented throughout the modeling domain. Other components are less certain because the model is limited in its ability to fully characterize the highly dynamic nature of the system, and especially the fate of organic matter, by lack of data. However, the process of developing this model and its components has been instrumental in developing a deeper understanding of water quality within the project and the response of water quality to change in both environmental conditions and management. This modeling tool, as it now stands, is capable of assessing complex questions about how Project operations and various meteorological, hydrological, and water quality conditions influence the environment of the Klamath river from Upper Klamath Lake to Turwar. Examples of the use of this model in assessing complex management options include:

- Characterizing existing water quality conditions in the Klamath River basin;

- Identifying the impacts of system wide steady flow regime (no peaking hydropower) on water quality;

- Assessing water quality conditions under a "without project" scenario, wherein the PacifiCorp hydropower facilities are removed and the system is modeled as a river from Link Dam to Turwar;

- Exploring of temperature management feasibility through selective withdrawal, temperature control curtains, and reservoir reoperation;

- Analysis of the impact of increased flows through the Bypass reach below J.C. Boyle dam on water temperatures associated with groundwater (springs) inflow;

- Exploring System Landscape Operations Management (SLOM) scenarios wherein selective Dams are removed and the impacts on flow and water quality assessed;

- Identifying the extend of Project effects below Iron Gate Dam under variable hydrological and meteorological conditions; and

- Identifying the role of boundary conditions (e.g., tributaries, return flows, diversions) on water quality conditions in the Klamath River basin.

3.5.1 Calibration Measures and Methods

Calibration required application of several alternative parameter sets and comparison of results against reported field conditions. Selection of final parameter values was based on graphical comparisons of simulated and measured data. Graphical comparisons were used to assess general model performance. These graphical comparisons provided significant insight, but could not be used to quantify differences over long time periods and at multiple locations along the river.

Flow calibration, including the technique of "iterative calibration" and the use of slope factors, is described below. Final parameter values from flow and water quality calibration have been included in Table 22 through Table 26.

Model calibration and validation depend upon field data for rigor. But there are inherent problems in using field data with a numerical model. Field data used to calibrate and validate the Klamath River Model, like all field data, describe field conditions with a certain significant amount of uncertainty. Heterogeneity of field conditions is a large factor in this uncertainty. Water quality can vary dramatically both spatially, within a water body, and temporally. Spatially, water quality may be influenced by proximity to shore, atmosphere, the bed, diversions, or to tributary sources and other inflows. Temporally, water quality is influenced by changes in light, temperature, and a range of biogeochemical processes that can range from sub-daily to seasonally or longer. Because sampling is necessarily limited in scope, often taken only periodically and at specific sites, field data provide an approximation of field conditions to guide calibration and validation of detailed numerical models. In this study, graphical analyses to show seasonal trends are the primary method of comparing field data to simulated results.

3.5.2 Flow Calibration

River reaches and reservoirs are calibrated differently for flow. River reaches are generally calibrated using an "iterative calibration" process and adjusting bed roughness and slope factors. Reservoirs are calibrated to reported water surface elevation.

3.5.2.1 River Reaches

Hydrodynamic calibration of river reaches typically requires varying channel roughness (e.g., Manning coefficient, n) through a range of values while comparing simulated transit time and river stage with measured data. Transit time can be estimated from stream velocity measurements or tracking changes in river stage under varying flow conditions. Although USGS gages are located near Seiad Valley (RM 129), Orleans (RM 56), and Turwar (RM5), travel time could only be roughly calibrated due to the long distance between gages and uncertainty in ungaged tributary flows and other accretions.

To calibrate long river reaches more accurately, Deas and Orlob (1997) developed a method for iterative calibration wherein hydrodynamic and water quality models were used jointly. Application of this method requires modeling on a sub-daily time step (e.g., hourly) and availability of associated sub-daily water temperature data. Both criteria were filled for this project. The method is outlined for the Klamath River in Appendix G.

Local bed slope over much of the length of steep rivers is generally significantly less than the overall gross slope of a river reach. This is because steep rivers are typically not uniform in slope, but consist of short cascades, or riffles, combined with intermediate pools and runs. RMA-2 includes a slope factor (SF) and associated logic that is designed to account for these changes in slope. The RMA slope factor reduces effective bed slope and assumes that travel time through the short cascade sections is negligible compared to the transit time through runs or pools. A short description of the slope factor and its application is presented in Appendix H.

Based on typical summer flow rates, slope factor was set at 0.80 for Link River, 0.90 for Keno reach, and 0.95 for the J.C. Boyle bypass-peaking reach. Two different slope factors were assigned to the Iron Gate to Turwar reach, representing significantly different geomorphology in the upper and lower sections of this reach. Slope factor was set at 0.80 for the upper section of

the reach between Iron Gate dam and Seiad Valley and 0.95 for the lower section of the reach from Seiad Valley to Turwar. Slope factors were modified slightly during calibration. Because slope factors are applied, consideration should be exercised before using this calibrated Manning coefficient in other flow models.

Results of the flow calibration of river reaches consist of comparison of total flow, velocity and stage. Results are compared to six USGS gage locations where stage and velocity data: Link River near Klamath Falls (11507500), Klamath River near Keno (11509500), Klamath River below J.C. Boyle Powerhouse (11510700), Klamath River below Iron Gate Dam (11516530), Klamath River near Seiad Valley (11520500), and Klamath River at Orleans (11523000). The Turwar gage is tidally influenced and not included in this assessment. Flow is effectively represented throughout the system and examining the stations in the Klamath River below Iron Gate dam indicates that travel time is reproduced. Velocity and depth are generally well represented, but there are deviations from measured data. These deviations, resulting from approximation of river geometry based on habitat studies (USWFS, 1997), are not expected to notably affect model results on a reach scale. Results of flow calibration (2000-01) and validation (2002-04) are presented graphically in Appendix I.

3.5.2.2 Reservoirs

As noted above, hydrodynamic calibration of the reservoir components of the Klamath River flow and water quality model was indirectly addressed by using reservoir storage to assess model flow performance. This mode of calibration (2000-01) and validation (2002-04) was completed for Keno, J.C. Boyle, Copco, and Iron Gate reservoirs. Reservoir stage is replicated in all years for all reservoirs. Simulated stage in Keno sometimes deviates from observed values (typically less than 1.5 feet (0.45 m), but these differences are not expected to affect model results. Graphical representation of simulated versus observed stage is included at the end of Appendix I.

3.5.3 Water Quality Calibration

The Klamath River Model has been calibrated against 2000 and 2001 water quality observations, and validated with 2002-2004 observations, at twenty water quality calibration-validation sites along its length. Data may not be available for all parameters at all sites for all years. Likewise, certain data are available for only a day or two over the calibration and validation period. The usefulness of presenting only a few data points over an extended set of modeling simulations such as these is limited when assessing model performance on a basin-wide scale for multiple years. As such, not all plots are presented or plots may show only a few data points or none at all. Calibration-validation sites that were considered throughout the modeling completed to date and their respective reaches are listed in Table 27. Results of calibration and validation are presented below, along with summary statistics. A compilation of summary statistics and a list of calibration parameters are presented at the end of this section. Graphical representations of model results and observed data at each site for each of the five years (2000-2004) simulated for this study are presented in Appendix J.

Table 27. Calibration and Validation Sites along the Klamath River

RM	Site	Reach	Notes
252.7	Link River at Lake Ewauna	Link River	Time series
244.7	Miller Island	L. Ewauna to Keno	Time series
234.3	Keno Reservoir at the Highway 66 Bridge near Keno	L. Ewauna to Keno	Time series
232.8	Klamath River below Keno Dam	Bypass and Peaking	Time series
227.8	Klamath River above J.C. Boyle Reservoir	Bypass and Peaking	Time series
224.3	J.C. Boyle Reservoir near J.C. Boyle Dam	Bypass and Peaking	Profiles, Time Series
224.2	Klamath River below J.C. Boyle Dam	Bypass and Peaking	Time series
220.2	Klamath River above J.C. Boyle Powerhouse	Bypass and Peaking	Time series
203.8	Klamath River above Copco Reservoir	Bypass and Peaking	Time series
198.6	Copco Reservoir	Copco	Profiles, Time Series
190.5	Iron Gate Reservoir	Iron Gate	Profiles, Time Series
190.4	Below Iron Gate Dam	Iron Gate to Turwar	Time series
177.5	Klamath River above Shasta River	Iron Gate to Turwar	Time series
129.0	Klamath River at Seiad Valley	Iron Gate to Turwar	Time series
57.6	Klamath River at Orleans	Iron Gate to Turwar	Time series
43.6	Klamath River above Trinity River	Iron Gate to Turwar	Time series
5.0	Klamath River at Turwar	Iron Gate to Turwar	Time series

3.5.3.1 Link River Reach

Temperature, dissolved oxygen and nutrient conditions were examined in light of available data. However, calibration and validation of this reach was completed based on available data, but due to the short length and transit time, only modest insight was gained through this exercise. Thus, water quality parameters were set for this reach based on simulation in much longer river reaches: Klamath River in the J.C. Boyle bypass-peaking reach and Iron Gate dam to Turwar reach. Most simulation results at the mouth of Link River mirrored boundary conditions at Link dam, just over one mile upstream.

Discussion

This short river reach is fairly insensitive to model conditions except when Link dam bypass flows are low and most water is passed through the Eastside and Westside powerhouses.

3.5.3.2 Lake Ewauna to Keno Dam Reach

The CE-QUAL-W2 model for Lake Ewauna to Keno Dam reach was calibrated and validated using water temperature, DO, and nutrient (phosphorous and nitrogen) data collected at Miller

Island and Hwy 66 near Keno. The model was calibrated to data collected during 2000-2001 and validated to data from 2002-04.

Calibration

Calibrated water temperatures generally match observed water temperatures. Observed temperatures sometimes exhibit greater range than simulated temperatures in summer months, but overall, diurnal range, short-term events (e.g., hot spells), and seasonal trends are well represented. Calibrated temperatures are typically higher than observed in summer and lower in winter at Hwy 66 near Keno. An external review of the model (Wells, 2004) provided input on under-prediction of winter temperatures, and several attempts were made to improve representation. Ultimately, the potential cause was estimated to be non-local meteorological data (i.e., not on-river meteorological conditions). A general trend towards low DO concentrations and high diurnal variation in summer is matched by calibration; but overall, simulated DO does not match observed hourly data. The range of simulated values can both under- and overestimate observation.

Observed nutrient concentrations are matched by simulated concentrations with overall range often good but with some elevated observations under-represented by simulation. Some distinct seasonal trends are well matched by simulation. Simulated algal peaks are elevated and timing occasionally off, but simulations match observed algal range and seasonal trend. Pattern of growth beginning in late spring and decline in fall is well represented, but some simulated algal concentrations can be considerably higher than reported values.

Validation

Water temperatures simulated during validation generally match observed water temperatures in value, diurnal range, and trend. Validated temperatures are typically higher than observed in summer and lower in winter at Hwy 66 near Keno. In validation, DO matches reported values much as it did in calibration. A summer pattern of oxygen depletion and re-oxygenation is matched by simulation, but simulated spring DO is considerably lower than reported for 2002.

Observed nutrient concentrations are fairly matched by simulated concentrations with overall range often good and summer rises in nutrient concentrations well represented. Reported concentrations of nitrates (as nitrogen; $N-NO_3$), typically low in 2002-03, are overestimated, as are orthophosphate (as phosphorus; $P-PO_4$) concentrations in 2003. A pattern of algae growth beginning in late spring and declining in fall is well represented by simulation. The range of observed values were matched by calibration at Miller Island, but simulated algal concentrations are considerably higher than reported values at Hwy 66 near Keno.

Discussion

The Lake Ewauna to Keno dam reach is a dynamic and complex reach to model for water quality. Water resources, including agricultural, municipal, and industrial activities, are intensively developed and occur adjacent to the river throughout much of this reach. Multiple diversions from the system supply industrial and agricultural use, and much of this flow is returned to the river after use. The Klamath River also receives municipal wastewater discharge.

Additionally, review of available literature and discussions with stakeholders suggest historical log rafting and timber industry practices have deposited considerable organic matter throughout the upper portion of this reach.

Impoundment of this reach and upstream Upper Klamath Lake has far-reaching consequences on water quality. Active management of storage in Upper Klamath Lake for summer use within the USBR Klamath Irrigation Project has reduced the frequency, and to some degree the magnitude, of winter flows through the Lake Ewauna to Keno dam reach. These reduced winter flows, coupled with impoundment at Keno dam and extensive restoration of local marshlands, have created a slow-moving waterway that encourages primary production of phytoplankton (as opposed to riverine forms of algae) and favors deposition. Upstream inputs from hypereutrophic Upper Klamath Lake, as well as historic and continued inputs from municipal, industrial, agricultural, and non-point discharges lead to significant oxygen demands within this reach.

Contemporary field work and review of data previously collected suggest that daily weak stratification, wind, withdrawals and return flows, a stable water surface (near constant storage), and a perceptible current (on the order of 0.05 to 0.2 feet per second at mid-channel) create complex conditions that directly impact water quality.

With the notable exception of water temperature, water quality in the Lake Ewauna-Keno Reach responds strongly to water quality of releases from Upper Klamath Lake. In fact, all downstream reaches are likewise strongly impacted by water quality conditions at Link dam. Water temperature is only moderately affected in downstream reaches because water in the system tends quickly towards equilibrium temperatures and water temperature in Upper Klamath Lake is generally already near equilibrium with the atmosphere.

Given the level of complexity encountered within this reach, simulation of temperature in this dynamic reach was by-and-large successful. Simulation of dissolved oxygen, nutrients, and algae, was not as successful because concentrations of these constituents depend so heavily on upstream boundary conditions at Link dam that are not well-defined. The model replicates seasonal dissolved oxygen concentrations, but short-term conditions are not always well represented.

Additional model simulations were completed to determine if algal populations, and thus DO and nutrients, would be affected if algal respiratory requirements were not met during anoxic periods and algae populations suffered accordingly. The model was modified to limit algal growth and increase mortality based on respiratory needs of phytoplankton. Specifically, if there was insufficient DO in the water column to support respiration of algae, algal mortality was increased. While there were no field data to test the model logic, sensitivity testing of model parameters while assessing phytoplankton, DO, and nutrient level responses indicated that algal respiratory requirements may not be the only factor behind the persistent anoxia, elevated nutrients and low algal counts that are prone to occur in this reach. Advection from upstream reaches tends to re-colonize downstream reaches on the order of days. Further research into this issue has focused on algal growth inhibition by one of several factors, potentially including impacts of pharmaceutical/human health and personal care products in municipal treated effluent, phenolic compounds associated with organic matter – including that within the

sediments (source: tannins, humic substances, lignin), production of hydrogen peroxide, other chemical constituents or reactions that may lead to inhibition or toxicity.

Another factor potentially affecting the spatial DO concentrations and distribution of phytoplankton is local meteorological conditions. Local meteorological data suggest that during summer periods afternoon winds are typical, especially in the vicinity of Keno. During the warmer periods of the year, daily afternoon wind events at Keno, located near the Klamath River canyon, are the norm. However, during these same periods, conditions are calm in much of the reservoir that lies east of Keno. Presence or absence of wind-driven mixing most likely has a direct impact on local phytoplankton populations and DO conditions.

Model performance for nutrients varies between year 2000 and 2001 applications. With the more complete data set of 2001, the model replicates observed conditions appreciably better than in 2000, when composite upstream boundary conditions were applied. Model performance during the validation period, when data are available for comparison, suggests results similar to the calibration period. The model has undergone a wide range of testing to assess its response to variable conditions and parameters.

3.5.3.3 Keno Dam to J.C. Boyle Reservoir Reach

The RMA-11 model of Keno River reach was not calibrated with 2000 and 2001 data due to data limitations. Instead, calibration relied largely on parameter values from the Iron Gate to Turwar reach and the J.C. Boyle bypass and peaking reaches. These longer river reaches provided more transit time to assess model performance. Light extinction was set specifically for this reach, based on light extinction measurements completed in 2004. The model was validated with available information from 2002-2003 below Keno dam and above J.C. Boyle reservoir.

Validation

Simulated water temperatures match monthly observations. Simulated summer temperatures tend to be modestly higher than those reported for summer months. The model typically represents a pattern of DO concentrations that begin to decline in spring, reach a low in summer, and climb back up in fall. Simulated DO is consistently lower than observations during spring and summer months below Keno dam and often lower than observations during spring above J.C. Boyle reservoir.

Simulations represent range and trend of observed nutrient concentrations, particularly ammonia (as nitrogen; N-NH3). Simulated N-NO3 and P-PO4 tend to be higher than reported during late summer through fall below Keno dam.

Discussion

Keno Dam to J.C. Boyle reservoir is a fairly short reach, with a transit time of a few hours. The models performed well in this steep river reach, replicating temperature, DO, and nutrient concentrations well. Under-prediction of winter temperatures persists through this river reach as a byproduct of the upstream model representation; but predicted values begin to improve as distance from Keno dam increases. Deviations between measured and observed DO below Keno

dam are probably due to factors associated with predicted DO in Keno reservoir, the effects of reaeration at Keno dam proper, and the dynamics of mechanical and biological reaeration in the river reach between Keno dam and J.C. Boyle reservoir. Reaeration occurs throughout this reach.

3.5.3.4 J.C. Boyle Reservoir

The CE-QUAL-W2 model of J.C. Boyle reservoir was calibrated and validated using water column profiles of water temperature, dissolved oxygen, and nutrient (phosphorous and nitrogen) reported at J.C. Boyle reservoir near J.C. Boyle dam. The model was calibrated to data collected during 2000-2001 and validated to data from 2002-2004.

Calibration

Calibration simulations reproduce values and trends in reported monthly profiles of water temperature with little deviation. The model simulates a slight seasonal gradient with depth noticeable in reported temperatures. Both simulated and reported temperatures show generally well-mixed, isothermal conditions throughout the year. Simulated DO concentrations generally fit observed data in spring and fall. The model reproduces a pattern of moderate hypolimnetic deoxygenation, observed in reported DO concentrations during summer months. But significant deviations occur in summer months of 2000 when simulated DO concentrations are often greater than observed at all depths. Profiles during periods of stratification can have greater than reported gradients. The model indicates depletion of DO in the hypolimnion in August 2001 that is not reflected in observations.

Although data are limited, simulated nutrient concentrations generally represent observed data fairly. With only a few exceptions, well-mixed, homogeneous conditions are indicated by both observed and simulated values. Simulated N-NO3 concentrations are often lower than reported concentrations. Generally, there is little variation in observed concentration from top to bottom of the reservoir and simulated algae concentrations reflect these well-mixed conditions. Simulations tend to overestimate algae concentrations in summer months.

Validation

Generally, validation simulations reproduce values and trends in reported monthly profiles of water temperature with little deviation. The model simulates generally well-mixed, isothermal conditions with a slight seasonal gradient noticeable in reported temperature profiles. Deviations from observation occur in August 2002 and in April and November of 2003, but these deviations appear to be short-lived. Simulated DO concentrations generally fit observed data in spring and fall. The model reproduces a pattern of moderate hypolimnetic deoxygenation, observed in reported DO concentrations during summer months. Gradients are reproduced, but significant deviations can occur in summer months when simulated DO profiles sometimes show depletion of DO at depth. Significant deviations appear to be short-lived in 2002, but are evident in spring and summer of 2003.

As in calibration, nutrient concentrations simulated in validation generally represent observed data fairly. With only a few exceptions, well-mixed, homogeneous conditions are indicated by both observed and simulated values. Simulated N-NO3 concentrations are often lower than

reported concentrations. The model reflects both trends and values of algae concentrations, showing well-mixed conditions and population growth in the summer and early fall.

Discussion

Critical factors affecting J.C. Boyle reservoir water quality include a short residence time, weak and intermittent stratification, and a large nutrient and organic matter load from upstream. Although the reach between Keno dam and J.C. Boyle reservoir provides an opportunity for mechanical reaeration, the reach is short and light limitation is appreciable, limiting the ability of the reach to oxidize material and capture nutrients. The short residence time creates a reservoir that is more like a slow, deep stream, suggesting that J.C. Boyle reservoir can be dramatically affected by short-duration events—deviating from a typical condition to an atypical condition and back again over the period of days. Wind mixing is another factor that may not be completely represented due to lack of local meteorological data. Such short-term events could affect stratification, mixing, and DO conditions within the reservoir.

3.5.3.5 J.C. Boyle Bypass-Peaking Reach

The RMA-11 model of J.C. Boyle bypass-peaking reach was calibrated and validated to data collected at Klamath River below J.C. Boyle dam, above the J.C. Boyle powerhouse, and above Copco Reservoir. Limited data were available at these locations in 2000 and 2001. As with the shorter river reaches upstream (Link River and the Klamath River between Keno dam and J.C. Boyle reservoir), insight was gained by examining calibration results from the longer river reach below Iron Gate dam.

Calibration

Water temperatures simulated in calibration match monthly observations in both value and trend. Simulated temperatures tend to be somewhat lower than those reported for winter months. Calibration simulations reproduce observed patterns of declining DO concentrations in spring, lows in summer, and rising concentrations in fall. Simulated concentrations match reported concentrations throughout 2000, but are consistently low in spring and summer of 2001.

Simulated concentrations of N-NH3 are lower than observed, but N-NO3 and P-PO4 are representative of reported values. Seasonal patterns of elevated concentrations in spring and summer are reproduced in simulations. Care must be used when interpreting results because peaking and non-peaking operations dramatically alter water quality below the J.C. Boyle powerhouse.

Validation

In validation years, water temperatures match observed data in both value and trend. Simulated temperatures at all validation sites in 2002 are modestly higher than reported values. DO concentrations simulated in calibration match trends in observed data. Generally, reported values are within the diurnal range of simulated values except in spring when simulated values tend to be low in comparison to reported values. Simulated values in the J.C. Boyle bypass reach approximate observed nutrient concentrations. N-NH3 is over-predicted in 2002. The model

results also indicate more variability in years when field data for nutrients show more variability. Downstream of the J.C. Boyle powerhouse, simulated levels of nutrients are likewise representative of field observations.

Discussion

The J.C. Boyle bypass-peaking reach experiences a highly dynamic flow regime and variable water quality due to peaking operations and the influence of a large springs complex. Modeling this steep reach required representing both physical features and short-duration hydropower operations. The models performed well for all parameters, although some of the peaking operations produced highly variable water-quality conditions. During processing of the 2003 data, numerical instability in some ammonia concentrations was identified. The overall impact was deemed not to adversely affect model results.

3.5.3.6 Copco Reservoir

The CE-QUAL-W2 model of Copco reservoir was calibrated to profiles collected within the reservoir near the dam in 2000-01. The model was validated with profiles from the same site collected in 2002 through 2004. Algae data for 2004 were not available for validation.

Calibration

The calibrated model effectively captures observed season variation in temperature profiles and water temperature gradients with depth. Simulated values are generally consistent with observation, except in the summer of 2001 when the model produces hypolimnetic temperatures that are warmer than observed, failing to capture the extent of summer stratification. The model matches DO concentrations in Copco reservoir when the reservoir is well-mixed in winter and spring. Summer stratification occurs, but simulated profiles during summer stratification in 2001 are more complex than observed profiles. The model captures oxygen depletion in the hypolimnion whenever it occurs and can accurately estimate the depth at which depletion occurs. But the model also produces depletion on both sides of summer, in June and October 2001, when none is observed.

Results from calibration simulations capture the general distribution of observed nutrient concentrations throughout the summer, when observations were made. The model generally reproduces the increase in N-NH3 and P-PO4 with depth. Simulated algae concentrations are representative of observed values. The model reflects reported data showing growth to occur predominantly in the upper layers of the reservoir. Simulated bloom begins in June 2001 when no algae were observed.

Validation

Water temperatures from validation simulations match observed values at all depths for the validation years. The model reproduces Copco reservoir's observed pattern of temperature stratification in the summer and de-stratification in the fall. When the reservoir is mixed, the calibrated model matches observed values at all depths. As stratification occurs, simulated results tend to overestimate DO concentrations in the hypolimnion. By late summer, the model again

matches observed DO profiles. The model captures oxygen depletion in the hypolimnion whenever it occurs and can accurately estimate the depth at which depletion occurs.

Validation simulations capture the general distribution of observed nutrient concentrations from spring through fall, when observations were made. The model generally reproduces the increase in N-NH3 and P-PO4 with depth during summer stratification and the mixing of the water column in late fall, as reflected in reported data. Simulated algae concentrations are representative of observed values. The model reflects reported data showing growth to occur predominantly in the upper layers of the reservoir. Occasionally, algae were observed at times when no simulated algae appear.

Discussion

Copco reservoir receives peaking flow from the J.C. Boyle bypass-peaking reach and releases peaking flows from Copco Dam for a significant portion of the year. These inflow and outflow operations have a notable affect on the reservoir thermal regime and water quality due to variable inflow temperature, quality, and rate, as well as variable outflow rates.

Although DO concentrations are over-represented in some years during certain periods of the year, these volumes are small and bottom waters do not, by and large, participate in day-to-day releases (or if so, in small quantities). When the reservoir mixes in the fall, its small hypolimnetic volume mixes into a much larger reservoir volume with minimal consequences. Low DO conditions in Copco reservoir probably have some bearing on autochthonous demand (algal mortality), but are most likely directly affected by the influx of organic matter and nutrients from upstream sources, which also serves to increase in-reservoir production. Hypolimnetic anoxia results in sediment release of ammonia and phosphorous. The model replicates this seasonal condition in years when it is present, and replicates the absence of this when it is absent.

3.5.3.7 Iron Gate Reservoir

The CE-QUAL-W2 model of Iron Gate reservoir was calibrated to profiles collected within the reservoir near the dam in 2000 and 2001. The model was validated with profiles from the same site collected in 2002 through 2004.

Calibration

Water temperature profiles from calibration simulations match observed profiles at all depths in all seasons except for consistent overestimation in the area of the thermocline during times of stratification. Observed top and bottom temperatures are closely and consistently matched by simulated values. When Iron Gate reservoir is mixed, in winter and spring, simulated DO concentrations generally reproduce observed concentrations. As the reservoir stratifies, both simulated and observed profiles exhibit similar shapes. However, from June into September, the simulated thermocline can be as much as 15 to 20 ft (4.5 to 6.0 m) lower than measured data for all years. DO in both simulated and observed profiles tend to be depleted in a water layer at, or around, the inflection point of the thermocline. Because simulated and observed thermoclines are different, the locations of these depletion layers are offset. Additionally, simulated DO

concentrations tend to be greater than observed concentrations in the hypolimnion. In fall, simulated DO profiles more closely resemble observed profiles and reproduce oxygen depletion in the hypolimnion.

Nutrient concentrations simulated during calibration generally reproduce observed concentrations and distributions, and are particularly representative of N-NH3 and P-PO4 in summer and fall of 2000. Simulated values reflect an increase in N-NO3 with depth, as reported, but tend to underestimate N-NO3 concentrations in 2001. Simulated algae concentrations are generally representative of observations, but the model tends to overestimate algae concentrations in late summer and underestimate concentrations in fall.

Validation

Water temperature profiles from validation simulations also match observed at all depths in all seasons except for consistent overestimation in the area of the thermocline during times of stratification. Observed top and bottom temperatures are closely and consistently matched by simulated values except in 2003 when simulated temperatures tend to overestimate temperatures observed in the hypolimnion. Validation results for dissolved oxygen are similar to calibration results. When the reservoir is mixed, simulated DO concentrations generally reproduce observed concentrations. As Iron Gate reservoir stratifies, both simulated and observed profiles exhibit similar shapes but the shapes are offset and distorted because simulated DO concentrations tend to be greater than observed concentrations in the hypolimnion. In fall, simulated DO profiles more closely resemble observed profiles and reproduce oxygen depletion in the hypolimnion.

Nutrient concentrations simulated during validation generally reproduce observed concentrations and distributions, and are particularly representative of all nutrients for all three sampling dates in 2003. Observed decreases in surface concentrations of N-NO3 during spring and summer months are reflected in simulation results. Generally, simulated algae concentrations are representative of observed values, but there are several dates in 2002 when observed algae do not show up in simulated results.

Discussion

There are several factors that warrant discussion with regard to Iron Gate Reservoir water quality. One point is the location of the thermocline in simulation results during the summer period. Sensitivity analyses were completed on the both the location of the lower fish hatchery intake and the quantity of water used by the fish hatchery. The simulated location of the thermocline is sensitive to both features. If the intake is raised even modestly (e.g., 10 feet (3m)), the simulated thermocline rises accordingly. Review of construction drawings suggest that the lower fish hatchery intake is properly represented. However, features of the intake may predispose waters to enter from higher in the reservoir (e.g., final constructed configuration). These possible features cannot be assessed because as-built drawings are unavailable. The feature more likely to be affecting simulations is the assumed hatchery intake rate. Based on conversations with hatchery staff, hatchery intake rate is currently assumed to be 50 cfs.

Low DO conditions in Iron Gate reservoir probably have some bearing on autochthonous demand (algal mortality), but are most likely directly affected by the influx of organic matter and

nutrients from upstream sources, which also serves to increase in-reservoir production. Improvement of the Link dam boundary conditions and accurate assessment of fish hatchery intake quantities would most likely improve simulations in Iron Gate reservoir.

3.5.3.8 Iron Gate to Turwar Reach

Like other reaches, the RMA-11 model for Iron Gate to Turwar was calibrated with 2000 and 2001 data and validated with 2002-2004 data. The discussion is presented generally by constituent and extends downstream to illustrate model performance in determining transport and fate of simulated constituents. Calibration and validation locations presented here include the Klamath River below Iron Gate dam, above the Shasta River, near Seiad Valley, at Orleans, above the Trinity River, and at Turwar. It is important to recall that these results have been passed through three river reaches and four reservoirs en route to Iron Gate dam. Thus, uncertainty in model results for this reach includes the sum of uncertainty introduced in upstream model representations.

Calibration

Water temperature from the CE-QUAL-W2 model of Iron Gate reservoir formed the upstream boundary conditions for the Iron Gate to Turwar Reach. Results from calibration years indicate that the model reproduced field-observed temperatures for sub-daily, short duration, and seasonal conditions. At sites in the upper part of the reach, the simulated diurnal range corresponds to measured data, but in the lower river the simulated diurnal range is suppressed. Overall, mean daily temperatures are similar to field observations at all locations.

DO conditions are underestimated below Iron Gate dam during summer and fall periods for both calibration years. Downstream locations, away from the influence of Iron Gate dam, are representative of field conditions in amplitude and timing.

Nutrients are generally well represented in the calibration period, although some scatter in the data is evident.

Validation

Results from validation years indicate that simulated temperatures match field-observed values for sub-daily, short duration, and seasonal conditions. However, in 2003 and 2004, model results underestimate temperature in the late winter and spring. At sites in the upper part of the reach, simulated diurnal range corresponds to measured data, but in the lower river, simulated diurnal range is suppressed. Overall, mean daily temperatures are similar to field observations at all locations.

DO concentrations are underestimated below Iron Gate dam during summer and fall periods for all three validation years. Downstream locations, away from the Iron Gate dam influence, are representative of field conditions in amplitude and timing but local deviations occur.

As with the calibration period, nutrients are generally well represented in the calibration period. Although there is some scatter in the field data, summer minimums for N-NO3 and seasonal

increases in N-NO3 and P-PO4 in the late summer and fall are clearly represented in simulated values.

Discussion

Water temperature below Iron Gate reservoir is moderated by a relatively deep release from Iron Gate reservoir. The model effectively reproduced this suppressed diurnal variation. It is also pertinent to note that immediately downstream of Iron Gate dam, simulated temperatures were not appreciably affected by the Iron Gate reservoir simulation wherein the thermocline was lower than observed during summer periods. Careful examination of the simulation suggests that much of the water leaving the reservoir is from the top 20 or 30 feet of the water column, where simulated thermal profiles are more similar to observations. In the validation period, simulated location of the Iron Gate reservoir thermocline appeared to have a larger impact than during calibration.

Progressing downstream, water temperatures begin to respond more to local meteorological conditions than to conditions at Iron Gate dam. Seasonal trends and responses to short-duration events are well represented. In some years, simulated diurnal range is more representative of observations than in others. In the lower river, where alluvial processes are dominant and channel form is highly variable, the trapezoidal cross-section may not fully represent actual conditions. Accurate representation of daily mean values indicates that tributary boundary conditions have been effectively specified and/or estimated.

Simulated DO concentrations are lower below Iron Gate dam than observations during summer and fall months. These conditions, largely due to simulated Iron Gate dam outflows are quickly remedied through mechanical reaeration. Model performance is more consistent with field observations at all downriver sites. Variability in diurnal range (both spatially and temporally) in both the simulated output and the prototype is due to complex interactions between nutrient availability, benthic algae growth, stream geometry, and light limitation. Although recent field campaigns have improved characterization of benthic flora, these interactions are incompletely understood. Algal biofouling of water quality probes further confounds efforts to characterize DO conditions by increasing uncertainty in field data. Nonetheless, model simulations show promising results.

Overall, simulated nutrients correspond to field observations along the longitudinal profile of the river, with higher-level and seasonal variations more prominent in the upper river reach and lower, less variable conditions in the lower reach. Reproduction of seasonal trends is evident in the model results. Phytoplankton populations are likewise well represented in all years where data are available.

One of the most critical aspects of the Iron Gate dam to Turwar calibration is the fact that these simulation results represent the end product of all upstream modeling. Results below Iron Gate dam, extending to Turwar, suggest that the model replicates a majority of system processes and effectively reproduces temperature, dissolved oxygen, nutrients, and algae. During processing of the data, numerical instability in some ammonia concentrations was identified. The overall impact was deemed not to adversely affect model results.

4.0 MODEL SENSITIVITY

Sensitivity analysis is a test of the impact that changes in a single model variable or parameter can have on model results. Such analyses can be used to identify important characteristics of a system. Sensitivity analysis can be used to:

- confirm that model response is consistent with theory,

- quantify the effect of error on state variables,

- identify sensitive parameters or variables that must be reliably estimated,

- indicate the relationship between control variables and decision (or state) variables to help ensure that a change in control variable can have a desirable effect on the decision variables, and

- identify regions of "design invariance" where target levels of decision variables are insensitive to errors of estimation in control variables and parameters.

The amount of sensitivity analysis that has occurred for the Klamath River modeling framework through the implementation, subsequent updates, and extension of the model for additional years is extensive. In this large, multifaceted, complex system a formal sensitivity analysis would be a large effort in itself. For this study, selected model parameters in both the RMA and CE-QUAL-W2 models were varied to determine the model's relative sensitivity to them. In this analysis, one model variable or parameter is changed while all others remain constant, and the impact of this change on a particular model state variable (e.g., temperature) is observed. Neither flow, water quality, nor meteorological boundary conditions were altered; however, during implementation these parameters were varied over a large range and model testing was extensive. Generally, parameters used in calibration were also tested for sensitivity.

This qualitative assessment gives an estimate of the sensitivity of important state variables to particular parameters, and provides insight on model performance (e.g., was model consistent with theory?). All parameter values were changed over representative ranges.

Conditions are highly variable throughout the Klamath River system and sensitivity varied by season and reach. Because reaction rates typically depend upon temperature and residence time, seasonal air temperature, flow, and reach length or volume had noticeable impact on sensitivity. Water quality typically shows less sensitivity to parameter change during cooler seasons, in shorter river reaches, and in reservoirs with less volume. Although presented herein as qualitative results, the actual model simulations were quantitative.

4.1 RMA PARAMETERS STUDIED FOR SENSITIVITY

Water quality in river reaches was tested for sensitivity to ten parameters. These ten parameters included the five variables used in calibration (roughness, slope factor, two evaporation constants, and light extinction) and the five other variables selected for their expected influence (reaeration rate constant, bed algae growth and respiration rate constants, atmospheric pressure,

and algal ammonia preference). Results of sensitivity testing in river reaches are outlined in Table 28. The tested parameters, as identified in model literature, are:

- n – Manning roughness coefficient

- SF – Slope Factor fraction to reduce bed slope of river to approximate water surface slope in solution of flow equations

- EVAPA, EVAPB – Evaporative heat flux constants

- RK2MIN – Minimum reaeration rate

- MUMAX – nominal bed algae growth

- RESP – bed algae respiration rate

- EXTINC – non-algal light extinction

- EA – atmospheric pressure

- PBREFN –algal preference for ammonia

For a full description of model parameters the reader is referred to the user's manual for RMA-2 and RMA-11 (King 2001, 2002).

Generally, water temperature was sensitive to bed roughness and slope factor, both parameters that directly impact travel (or, residence) time through the river reaches. Temperature was also highly sensitive to the evaporative heat flux parameters. In addition, temperature response was tested under different geometric representations of the system. Specifically, temperature output from several reaches was examined while varying river width and side slope. Impacts resulting from moderate geometric changes were generally modest, with the notable exception that marked changes in river width can dramatically impact travel time and thus water temperature. Changing nodal resolution of the models from 75 meters and 150 meters had negligible effect on water quality.

DO was sensitive to minimum reaeration rate and highly sensitive to algal growth and respiration parameters. In particular, if minimum reaeration rate is set too high, an excess of respiration occurs. Nutrients were generally low-to-moderately sensitive to algal growth parameters, but ammonia and nitrate concentrations were sensitive to ammonia preference factor. Nutrients were moderately sensitive to light extinction in certain river reaches because, under high extinction rates, benthic algal growth was light limited and nutrient uptake suppressed. Algal concentrations were very sensitive to growth rate, respiration rate, and light extinction.

Table 28. RMA-11 Water Quality Constituent Sensitivity to Different Modeling Parameters

Parameter	State variable					
	Temperature	DO	PO4	NH4	NO3	Algae
Manning n	H	-	-	-	-	-
SF	H	-	-	-	-	-
EVAPA	H	L	-	-	-	-
EVAPB	H	L	-	-	-	-
IREAER*	N	H	N	L	S	-
MUMAX	N	H	N	L	S	H
RESP	N	H	N	-	-	H
PBREFN	N	-	N	M	M	L
EXTINC	N	M	-	L	L	H
EA	N	L	-	-	-	-
Bathymetry	M	L	-	-	-	-

N– no sensitivity

L– low sensitivity

M– moderate sensitivity

H– high sensitivity

If there is no letter in the space, the constituent was not tested for sensitivity to the parameter.

4.2 CE-QUAL-W2 PARAMETERS STUDIED FOR SENSITIVITY

4.2.1 Assessment

Twenty parameters were tested for their impact on water quality in reservoir reaches modeled by CE-QUAL-W2. These twenty parameters included a wide range of parameters selected for their demonstrated influence on water quality. The tested parameters, as identified in model literature, are:

- AFW, BFW, and CFW - Evaporative heat flux coefficients

- AG - Algal Growth Rate

- AR - Algal Respiration Rate

- AM - Algal Mortality Rate

- ASAT - Algal light saturation intensity at the maximum photosynthetic rate

- SOD- Sediment Oxygen Demand

- CBHE - Bed heat conduction coefficient

- TSED - Specified bed temperature: TSED

- EXSS Light Extinction due to inorganic suspended solids:

- EXOM - Light extinction due to organic matter

- EXH20 - Light extinction due to water

- EXA - Light extinction due to algae

- BETA - Solar radiation absorption fraction: the BETA parameter is the fraction of incident solar radiation absorbed at the water surface

- LDOMDK - Labile organic matter decay rate

- POMS - Particulate organic matter settling rate

- NH4DK - Ammonia decay rate

- NO3DK - Nitrate decay rate

- O2LIM - Aerobic/anaerobic oxygen Limit: user defined oxygen limit refers to the concentration below which anaerobic processes begin to be simulated.

Results of sensitivity testing in reservoir reaches are outlined in Table 29. Generally, temperature was sensitive to evaporative heat flux parameters. In the deeper reservoirs (i.e., Copco and Iron Gate), impacts were observed over longer periods than in the shallow reservoirs (i.e., Keno and J.C. Boyle). In deeper reservoirs with longer residence time, bottom water temperature was moderately sensitive to bed heat exchange coefficient.

DO was sensitive to algal growth, respiration, and mortality. Parameters affecting algal growth, such as the various light extinction parameters, also affected dissolved oxygen concentrations. In reservoirs with long residence times, organic matter decay rates noticeably impacted DO concentrations. DO sensitivity to ammonia decay rate was low.

Nutrients were generally low-to-moderately sensitive to algal growth parameters and associated parameters such as extinction, and nitrate was notably more sensitive to these parameters than ammonia. Algal concentrations were very sensitive to growth rate, respiration rate, and light extinction.

Table 29. CE-QUAL-W2 Water Quality Constituent Sensitivity to Different Modeling Parameters

Parameter	State Variable					
	Temperature	DO	PO4	NH4	NO3	Algae
AFW	M	-	-	-	-	-
BFW	M	-	-	-	-	-
CFW	L	-	-	-	-	-
AG	N	L	L	L	H	H
AR	N	M	L	L	M	H
AM	N	M	L	L	M	H

Table 29. CE-QUAL-W2 Water Quality Constituent Sensitivity to Different Modeling Parameters

Parameter	State Variable					
	Temperature	DO	PO4	NH4	NO3	Algae
ASAT	-	-	-	-	-	-
SOD	N	M	M	N	N	L
CBHE	M	-	-	-	-	-
EXSS/EXOM	N	H	L	L	M	H
EXH2O	N	H	M	L	M	H
BETA	N	H	M	L	M	H
EXA	N	H	L	L	H	H
LDOMDK	N	M	L	L	L	N
POMS	N	L	L	L	L	N
NH4DK	N	L	N	L	L	N
NO3DK	N	N	N	N	M	N
O2LIM	N	N	M	N	L	N
Bathymetry	H	H	H	H	H	H

N – not sensitive

L – low sensitivity

M – moderate sensitive

H – high sensitivity

If there is no letter in the space, the constituent was not tested for sensitivity to the parameter.

4.3 OTHER CONSIDERATIONS

As noted above, the model was tested widely throughout the implementation and calibration phase, as well as during model modification, update, and application. Outlined below is a brief discussion of selected aspects of the modeling framework that were tested and considered while completing the various simulation and modeling tasks.

4.3.1 System Geometry

A number of modifications to the geometry of river and reservoir reaches were made during model development and implementation. Additional resolution was added to all reservoirs with the exception of Keno reservoir to assess sensitivity to layer thickness. The models in general are sensitive to layer thickness and simulation results improved (as compared to measured data) in all cases with finer layer thickness to a point where further refinement yielded no additional benefit. At this point the balance of computational effort and grid resolution was examined and final layer thickness selected. For example, at J.C Boyle reservoir a 1.6 ft (0.5m) thick layer versus a 3.2 ft (1.0 m) layer made a 20 hour difference in the model's run time because, at the small layer thickness, the model continually added and subtracted segments in response to peaking operations. Additional simulations with different segment lengths and layouts were completed as well. Lake Ewauna-Keno reservoir was tested using three bathymetric

representations: the original bathymetry from ODEQ (1995), a fictitious bathymetry to determine if model results were sensitive to a different geometry, and new bathymetry from a 2003 survey (PacifiCorp, 2004a). Findings suggest that water quality in this reservoir is sensitive to bathymetry and that using the best available data is important in effective representation. The 2003 data (PacifiCorp, 2004a) are currently used in the model.

River reaches were likewise examined in terms of inter-node distance, cross sectional width, and side slope. Both 490 ft (150 m) and 246 ft (75 m) inter-node distances were examined. In most reaches, a 246 ft spacing was selected, but for the longer Iron Gate to Turwar reach a 490 ft spacing was used because the differences in simulated output between the two node spacing were negligible and the run time was reduced by 50 percent. In addition, different river widths were examined in the J.C. Boyle bypass-peaking reach, Keno reach, and Link River reach prior to field data becoming available. These early runs were instrumental in our understanding of the importance of incorporating field data into our geometric representation.

4.3.2 Meteorological Data

Both during implementation and during subsequent updates, various meteorological specifications were attempted and model response assessed. Initially, Klamath Falls data was used for the entire system, with corresponding lapse rates applied to selected parameters. This approach was abandoned in favor of meteorological data from site specific locations along the river. However, there were multiple meteorological stations which required the river to be broken down into discrete reaches where meteorological conditions would be applied. The entire river network was run under various conditions (as well as discussions with local basin residence) to identify which meteorological conditions would apply to which reach. Throughout this process, multiple runs were completed and the model sensitivity assessed. Overall, in the short river reaches, meteorology had a modest impact. The longer river reaches and the long residence time reservoirs responded more strongly.

4.3.3 Flow

Flow conditions were largely taken from field observations and was widely tested during calibration. The river flow model was most sensitivity to the bed roughness and slope factor, as expected. The reservoir models were most sensitive to geometric presentation. Because the inflow and outflow are explicitly specified, there is little to assess beyond stage. Overall, the reservoir applications were insensitive to bed roughness.

4.3.4 Water Quality

The range of water quality parameters used in model testing the various reaches, seasons, and years creates hundreds of possible permutations. As noted above, the reaches were initially modeled independently then combined into the framework. Model parameters were modified and tested over multiple iterations to identify system response and to compare results with field data. Impacts of changes to model parameters and boundary conditions were explored at Link dam and inflows to Keno reservoir to assess their local impacts, as well as translating those impacts through all downstream reaches.

4.4 SUMMARY

Water quality modeling parameters most influential in prediction of water temperature and DO are similar for both RMA-11 and CE-QUAL-W2:

- Water temperature is most sensitive to evaporative heat flux parameters, and

- DO and algae concentrations are most sensitive to algal growth dynamics and light extinction.

It is useful to note that these are common calibration parameters in water quality modeling. Based on all of these tests, the models were updated or modified to best characterize the Klamath River system.

5.0 MODEL APPLICATION

The Modeling framework has been applied to several scenarios identified by PacifiCorp and stakeholders. These include but are not limited to:

- Existing Conditions (EC)

- Steady Flow (no hydropower peaking) (SF)

- Without Project facilities (WOP)

- Without Project facilities, smoothed flows from Klamath Irrigation Project (WOP II)

- Without Iron Gate dam (WIG)

- Without Iron Gate, Copco 1, and Copco 2 dams (WIGC)

- Without Iron Gate, Copco1, Copco2, and J.C. Boyle dams (WIGCJCB

- Selective withdrawal at Iron Gate reservoir only

- Selective withdrawal at Copco reservoir only

- Selective withdrawal at both Copco and Iron Gate reservoirs

- Reservoir curtains at Copco and Iron Gate reservoirs

- Flow augmentation via drawdown of Copco and Iron Gate reservoirs

- Variable J.C. Boyle releases to the bypass reach

Results from these scenarios have been produced in tabular form, and in some cases graphical form, for 26 sites identified by Stakeholders (Table 30).

These scenarios have been developed and documented through stakeholder meetings, technical memoranda, and other reports. The individual applications are not detailed herein, but rather the reader is referred to specific documents addressing the scenarios.

Table 30. Modeling Framework Reporting Location (For Existing Conditions)

Location	River Mile	Model Node (Seg)*
Link Dam	253.88	1
Link River at LE	252.67	27 (2)
RM 248	248	(26)
RM 243	243	(53)
RM238	238	(79)
Keno Dam	232.86	1 (107)
Above JC Boyle	227.57	115
JC Boyle Dam	224.32	(21)

Table 30. Modeling Framework Reporting Location (For Existing Conditions)

Location	River Mile	Model Node (Seg)*
bel JC Boyle Dam	224.32	1
Above Powerhouse	220.2	91
Below Powerhouse	220.02	95
Stateline	209.16	331
Above Copco	203.6	451 (18)
Irongate Dam	190.54	1 (31)
Above Shasta River	177.52	142
At Walker Bridge	156.79	369
Above Scott River	143.86	511
At Seiad Valley	129.04	672
Above Clear Creek	99.04	998
Above Salmon River	66.91	1352
At Orleans	57.58	1454
Above Bluff Creek	49.03	1547
Above Trinity River	43.33	1609
At Martins Ferry	39.5	1651
At Blue Creek	15.95	1908
At Turwar	5.28	2024

* Nodes are associated with the river models RMA-2 and RMA-11, while
  segments are associated with the reservoir model CE-QUAL-W2. Point of
  common locations are denoted by both a node and segment number.

6.0 CONCLUSIONS

All system components have been calibrated to available data in spring, summer, and fall. Lack of data precluded formal calibration of the models during winter months. In complex systems like the Klamath River, additional information and model testing are always recommended but, with calibration and validation done to date, the Klamath River modeling framework is considered complete. The Klamath River model and its individual components have been extremely effective at illustrating flow and water quality processes throughout the system. System characterization, model implementation, sensitivity testing, and calibration have resulted in a greatly improved understanding of Klamath River flow and water quality.

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Personal Communications

Eilers, Joe. J.C. Headwaters Inc.
Flug, Marshal. U.S. Geological Survey, Ft. Collins CO
Olson, Todd. PacifiCorp